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ACUTE TOXICITY OF SEVEN ALICYCLIC HEXANES TO STRIPED BASS, *MORONE SAXATILIS*, AND BAY SHRIMP, *CRANGON FRANCISCORUM*, IN SEAWATER¹

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Field monitoring studies have shown that many striped bass, *Morone saxatilis*, in California's Sacramento-San Joaquin Estuary are burdened with a wide variety of pollutants including many types of petroleum hydrocarbons. Alicyclic hydrocarbons are among these pollutants but there was no information on their toxicity to striped bass. Our studies were concerned with the acute toxicities of the simplest alicyclics in comparison to their counterparts in the aromatic series. The alicyclic compounds were cyclohexane, methylcyclohexane, ethylcyclohexane and four dimethylcyclohexanes (1,1; 1,2; 1,3; and 1,4). Acute toxicities after 24 and 96 h exposures to seven alicyclic hexanes were determined for striped bass and one of their major food organisms, the bay shrimp, *Crangon franciscorum*. The 96 h LC₅₀s for striped bass and bay shrimp ranged from 3.2 to 9.3 µl/l and from 1.0 to 6.2 µl/l, respectively. Slight differences were noted between the 24 and 96 h LC₅₀ values in all but two bioassays. Solubilities of these alicyclics in seawater and freshwater were determined since information in the literature was limited. Solubility was inversely related to the complexity of the alicyclic structure and ranged from 5.3 to 62 µl/l in distilled water and from 4.6 to 44 µl/l in seawater. Alicyclics were generally more soluble in distilled water than in seawater. Tissue analyses showed greater bioaccumulation in striped bass, which have more lipid than bay shrimp. Striped bass had up to 260 µl/kg (wet weight) of an alicyclic hexane after exposure to water concentrations ranging from 0.32 to 12 µl/l. Bay shrimp residues were as much as 110 µl/kg of an alicyclic hexane.

INTRODUCTION

Alicyclic hexanes were recently found in liver and ovary tissues (0.02 to 16 µl/kg wet weight) of striped bass, *Morone saxatilis*, taken from the Sacramento-San Joaquin Estuary (Whipple, Eldridge and Benville 1981). Along with monocyclic aromatic hydrocarbons, the alicyclics were associated with poor physiological conditions (egg resorption and lesions with cestode larvae) leading to possible organ dysfunctions. Because little information exists on the toxic effects of these petroleum compounds, we conducted a series of experiments to determine the toxicological consequences of alicyclic hexanes to striped bass and bay shrimp, *Crangon franciscorum*.

Alicyclic hexanes are six-carbon ring structures in the cyclic aliphatic hydrocarbon class (cycloalkanes) of organic compounds which are relatively nonpolar and have low solubility in water (Morrison and Boyd 1966). Seven low molecular weight alicyclic hexanes found in the tissues of striped bass collected from the San Francisco Bay were selected for acute toxicity tests. These alicyclics were: cyclohexane, methylcyclohexane, four dimethylated forms 1,1-; cis- and trans-1,2-; cis-1,3-; and cis- and trans-1,4-dimethylcyclohexane (DMCH), and ethylcyclohexane (ECH) (Figure 1).

¹ Accepted for publication August 1984.

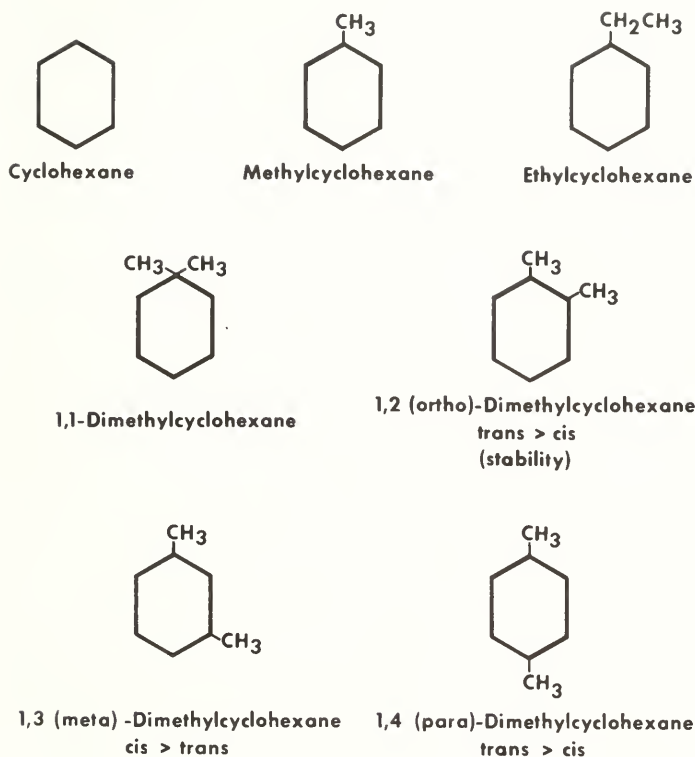


FIGURE 1. Structural formulas of seven alicyclic hexanes.

While some alicyclics entering the aquatic environment are of biogenic origin (e.g. plant metabolites), most alicyclics are from anthropogenic sources such as oil spills and waste discharges.

MATERIALS AND METHODS

Solubility Determinations

The lack of published solubility values for most of the seven alicyclics necessitated the determination of their solubility in distilled water and seawater before we could conduct the toxicity experiments.

To determine the solubilities of the seven alicyclics, saturated solutions were prepared by shaking 0.22 ml of each alicyclic with 220 ml water in a 250 ml separatory funnel for 1 min and letting the mixture settle for 24 h at 20° C. Two 100 ml portions of the saturated water extracts were drained into 125 ml separatory funnels; each portion was extracted in succession with three 10 ml aliquots of TF-Freon (trichlorotrifluoroethane) (Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.). Samples were processed as described under Analytical Procedure, below.

Bioassay Procedure

Juvenile striped bass (mean weight = 8.5 g, mean total length = 9.2 cm) were obtained from freshwater at the U.S. Bureau of Reclamation fish screening facility at Tracy, California, and acclimated to seawater at our laboratory in Tiburon, California. Bay shrimp (mean weight = 1.7 g, mean length = 6.4 cm), were acquired from a local bait dealer in San Rafael, California. Mortality from transportation and salinity change during the first 24 h was 20% for striped bass and less than 1% for bay shrimp. All animals were held in flow-through 200 l tanks for 2 wk before toxicity testing (Korn 1975). Mortality during this period was less than 1% for both fish and shrimp. Salinity and temperature of the seawater increased during the holding period from 27 to 32 ‰ and 15 to 20°C, respectively.

Static bioassays were conducted with each alicyclic using five oval fiberglass aquaria with dimensions of 110 cm length × 50 cm width × 40 cm height. Each aquarium was filled with 180 l of filtered seawater. Five alicyclic aliquots ranging in geometric progressions from 1 to 16 ml were mixed with seawater to achieve the necessary nominal concentrations. Test-tank solutions were prepared by adding the alicyclics slowly (8 ml/min) into a mechanically-generated seawater vortex. Immediately after the appropriate amount of alicyclic was introduced into each aquarium, ten animals of each species were placed in each aquarium. No aeration was used during the testing period. The bay shrimp were separated from the fish by placing them in a 30 cm length × 16 cm width × 14 cm height basket. Two 10 ml seawater samples were pipetted at mid-depth from each aquaria before and after introducing the animals to determine the alicyclic concentrations. These samples were immediately extracted with 10 ml of TF-Freon and analyzed as described under Analytical Procedure. Each succeeding day a 100 ml water sample was taken, extracted and analyzed. Mortalities were noted daily. Bioassay procedures followed were from Standard Methods (Connors, Jenkins and Greenberg 1981). LC_{50} s and confidence limits were calculated by the Litchfield and Wilcoxon (1949) method.

All fish and shrimp were analyzed for alicyclic residues at the end of the 96 h tests. Animals were frozen using dry ice and ground into a powder (Benville and Tindle 1970). A composite of 10 g homogenized tissue was then processed for alicyclic concentrations (Nunes and Benville 1979).

Analytical Procedure

The alicyclics in each Freon extract were separated and analyzed with a Hewlett-Packard 5880 gas chromatograph (GC) equipped with a dual flame ionization detector. Standard solutions of each alicyclic hexane were made for calibrating the GC. A combined standard was made from the seven alicyclics, six monocyclic aromatics and nonane to determine the relative location of each compound (Figure 2). The six aromatics were benzene, toluene, ethylbenzene and three xylene isomers (ortho-, meta, and para-). All alicyclics were eluted from the Bentone-34/SP-1200 column at 65°C within 8 min. After all the alicyclics were separated, the temperature was increased to 120° C to remove all the aromatics. There were overlapping retention times between the DMCHs and ethylcyclohexane (ECH) using the Bentone-34/SP-1200 column. However, each bioassay involved only a single alicyclic and analytical interferences were not encountered. Benzene was eluted within the alicyclic group but caused no

interference. Temperature programming was started after 10 min. running time to elute the ethylbenzene and xylene isomers within a reasonable time frame (15 min). The four dimethylated alicyclics and ethylcyclohexane had overlapping retention times and emerged in the following three groups: 1,1-DMCH, cis-1,3-DMCH and trans-1,4-DMCH; trans-1,2-DMCH and cis-1,4-DMCH; and cis-1,2-DMCH and ECH. No trans-1,3-DMCH was available for standardization; consequently its elution time was unknown. One unknown peak appeared at 2.653 min which was an inherent characteristic of the TF-Freon solvent. The ratio of the cis- and trans-isomers that appeared for 1,2-, 1,3- and 1,4-DMCH were 41/59, 100/0 and 25/75, respectively. Alicyclic data reported in ppm are in $\mu\text{l/l}$ for water sample and $\mu\text{l/kg}$ for tissue samples based on wet weight.

RESULTS

Solubilities

All seven alicyclics had solubilities in the low ppm range (Table 1). The number of alkyl groups on the cyclohexane compounds is in inverse proportion to its water solubility, with cyclohexane the most soluble and dimethyl and ethyl alicyclics the least soluble. In general, the position of the methyl groups appears to affect the solubility. The further apart the two groups were from each other, the less soluble was the DMCH. Solubilities also changed with salinity. Alicyclics, except for ECH, were more soluble in distilled water than in seawater; ECH had the same solubility in both distilled water and seawater. Solubility values ranged from 5.3 to 62 ppm in distilled water and from 4.6 to 44 ppm in seawater. The solubility of most of the alicyclics in seawater was lower by 24 to 29%; cis-1,3-DMCH had only a 10% reduction and there was no change for ECH. Ratios of the two optical isomers (cis- and trans-) in 1,2- and 1,4-DMCH compounds were altered slightly favoring the cis- form after they were dissolved in water, from 41/59 and 25/75 to 45/55 and 30/70 for distilled water and 44/56 and 28/72 for seawater, respectively.

Acute Toxicity and Tissue Residues

The alicyclics were more toxic to bay shrimp than to striped bass (Table 2). Acute toxicities of the seven alicyclics ranged from 4.7 to 10.9 ppm for striped bass and from 1.5 to 6.5 ppm for bay shrimp within a 24 h period. The 96 h tests showed slightly higher toxicities, although cyclohexane for striped bass and 1,3-DMCH for bay shrimp had similar acute toxicities for both exposure periods. Mixtures of the cis- and trans-DMCH (1,2- and 1,4-) isomers were more toxic to both striped bass and bay shrimp than the two pure DMCH's (1,1- and 1,3-). Acute toxicity values (LC_{50}s) of ECH, 1,3-DMCH and 1,4-DMCH for striped bass exceeded the solubility of the compound in seawater; for bay shrimp, only the LC_{50} for ECH and 1,3-DMCH exceeded the seawater solubility.

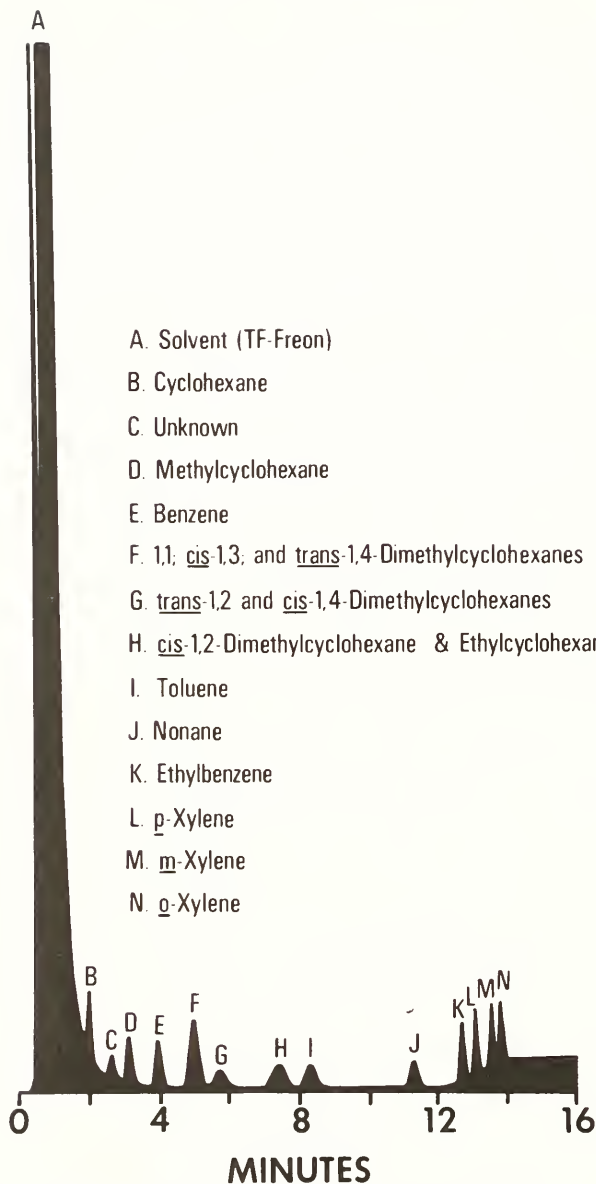


FIGURE 2. Chromatogram of nine alicyclics, six aromatics and nonane.

The striped bass and bay shrimp rapidly bioaccumulated the alicyclics many times above the initial water dosage. Test concentrations of alicyclics in seawater ranged from 0.32 to 11 ppm which resulted in uptakes by striped bass from "nondetectable" levels to 260 ppm (wet weight) and by bay shrimp from 4.4 to 110 ppm (Table 3). Water insoluble alicyclics were accumulated to higher levels by the organisms than were the more soluble ones.

TABLE 1. Physical Properties of the Alicyclic Hexanes.

Compounds	% Purity	Solubility (ppm) @ 20°C		% Optical Form *	Molecular weight	Boiling point (C)	Density (g/ml)	Vapor † pressure (mm Hg)
		Distilled	Seawater (cis-/trans-)					
Cyclohexane	99+	62	44	—	84.16	81	.77	78
Methylcyclohexane	99	18	13	—	98.19	101	.77	36
Ethylcyclohexane	99+	5.3	5.3	—	112.22	103-132	.778	10
1,1-Dimethylcyclohexane	97	10	7.6	—	112.22	118-120	.777	17
1,2-Dimethylcyclohexane	98	8.2(3.7/4.5)	6.1(2.7/3.4)	41	112.22	124	.778	11 (cis-)
1,3-Dimethylcyclohexane	99	6.2	5.6	100	112.22	120	.784	16 (cis-)
1,4-Dimethylcyclohexane	98	6.4(1.9/4.5)	4.6(1.3/3.3)	25	112.22	120	.773	14 (cis-)

* Analyzed by gas chromatography (not corrected for purity).

† Values were calculated for 20°C using Antoine equation in Lange's Handbook of Chemistry (Dean 1979).

TABLE 2. Acute Toxicity of Seven Alicyclic Hexanes to Striped Bass and Bay Shrimp.

Alicyclic Hexanes *	Striped Bass			Bay Shrimp		
	24-h		96-h	24-h		96-h
	LC ₅₀	95% C.L.		LC ₅₀	95% C.L.	
Cyclohexane	8.3	—†	8.3	3.4	—	2.4
Methylcyclohexane	7.0	5.7-8.6	5.8	3.5	3.0-4.0	3.3
Ethylcyclohexane	10.9	6.6-17.5	8.8	3.7	2.9-4.8	3.1
1,1-Dimethylcyclohexane	7.5	6.6-8.5	6.9	6.5	6.1-6.9	5.2
1,2 Dimethylcyclohexane	4.7	3.2-6.9	3.2	1.5	0.82-2.6	1.0
1,3 Dimethylcyclohexane	9.9	8.3-11.8	9.3	6.2	5.5-6.9	6.2
1,4 Dimethylcyclohexane	6.7	6.0-7.3	6.5	2.8	2.0-3.8	1.5

* 1,2 and 1,4 dimethylcyclohexanes are mixtures of cis and trans isomers.

† No confidence limits were calculated from bioassays without partial mortalities.

TABLE 3. Resulting Concentrations of Alicyclic Hexanes in Tissues of Striped Bass and Bay Shrimp from Test Containers.

Alicyclic Hexanes *	Concentration Range of Alicyclics (ppm)		
	Water (v/v)†	Striped bass (v/w)	Bay shrimp (v/w)
Cyclohexane	.54-10	N.D.‡- 48	4.4- 6.9
Methylcyclohexane	.54- 7.3	N.D.‡-130	16 - 26
Ethylcyclohexane	1.5 -11	5.8- 63	8.5- 66
1,1 Dimethylcyclohexane	1.5 - 8.7	23 -170	9.1-110
1,2 Dimethylcyclohexane	.32- 7.9	1.1-260	24 - 47
1,3 Dimethylcyclohexane	1.6 -12	6.5-160	7.0-100
1,4 Dimethylcyclohexane	1.2 - 7.1	28 - 46	12 - 36

* 1,2 and 1,4 dimethylcyclohexanes are mixtures of cis and trans isomers.

† v = Volume, w = Weight, Initial dosage

‡ N.D. = Non detectable below 0.7 µl/kg for tissue sample.

We noted that striped bass were more docile, easier to net and transfer after the 96 h testing period than before the dosing began. Striped bass exposed to the high dose of 1,3-DMCH (12 ppm) swam in tight clockwise circles instead of swimming around the aquaria like the control fish when the aquaria were disturbed. Some fish dosed with other alicyclics at lower concentrations would do the same but not as long (only 10-15 s).

DISCUSSION

The acute toxicity (24 h bioassay) of the alicyclics to striped bass and bay shrimp was in the low ppm range (1.5 to 10.9 µl/l) which is considered moderately toxic to fish and invertebrates relative to other compounds (Benville and Korn 1977). Extending the toxicity testing interval 3 more days resulted in increases in the toxicity of all bioassays except for two tests (striped bass/cyclohexane and bay shrimp/1,3 DMCH). The slight increase in toxicity was probably due to the delayed effects of the alicyclics since alicyclics rapidly escape from solution, resulting in alicyclic concentrations too low to cause acute effects. Using a continuous flow method of dosing would probably show higher toxicities (lower LC₅₀s). Static tests usually result in higher LC₅₀ values (lower toxicity) than continuous dosing because the concentration of the toxicant is decreasing and not being replenished using the static method.

Three of the alicyclics (ECH, 1,3 DMCH and 1,4 DMCH) had solubility values below their LC₅₀ concentration values for striped bass (Figure 3). Researchers usually use a solubilizing agent to disperse "insoluble" toxicants without knowing the effects of the solubilizers. Therefore, we did not use any dispersing agents in this study.

Striped bass appeared to be more sensitive to alicyclics than other fish species that have been tested. Pickering and Henderson (1966) reported 96 h TLms (median tolerance limits) of cyclohexane for fathead minnows, *Pimephales promelas*; bluegills, *Lepomis macrochirus*; goldfish, *Carassius auratus*; and guppies, *Lebistes reticulatus*, of 42, 45, 55 and 75 µl/l, respectively. These are 5 to 9 times higher than the toxic levels to striped bass. Jenkins, Klein and Cooper (1977) found an LC₅₀ of 84 µl/l for methylcyclohexane with golden shiners, *Notemigonus chrysoleucas*, 14 times the level of toxicity for striped bass. Although little data are available on the toxicity of higher homologs of cyclohexane

to fish, mammals show an increase in the narcotic action and toxicity when alkyl groups are added to cyclohexane (von Oettingen 1942). We found that MCH, 1,1 DMCH, 1,2 DMCH and 1,4 DMCH were narcotic to striped bass. Perhaps ECH and 1,3 DMCH also would have been narcotic if their solubilities were higher.

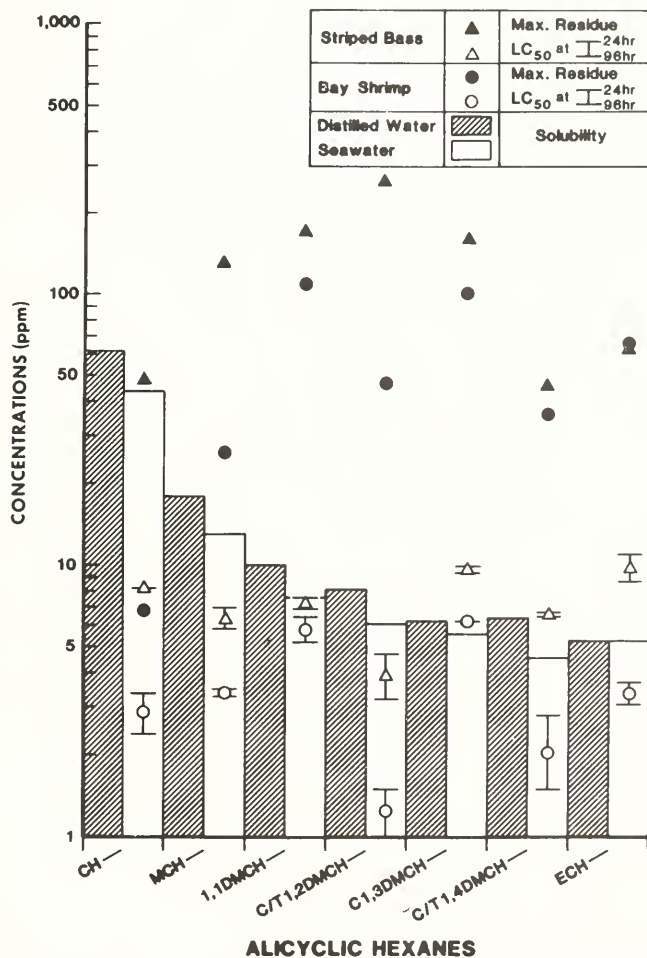


FIGURE 3. Solubilities, acute toxicities and maximum tissue residues of seven alicyclic hexanes.

Alicyclics bioaccumulated in striped bass and bay shrimp by factors of 33x and 13x, respectively. The greater accumulation in striped bass is due primarily to their higher lipid content. Alicyclic residues might have been much higher, as our research has indicated with monocyclic aromatic hydrocarbons (Whipple *et al.* 1981), if the samples were taken at the optimum exposure time. Aromatics accumulate rapidly in aquatic animals. Benzene (the simplest aromatic) accumulated in high concentrations in striped bass shortly after 40-min

exposure (Whipple *et al.* 1981). A 1.5x to 119x increase above the ambient water concentration of benzene was noted depending on the tissue analyzed. Muscle had the lowest uptake and fat the highest uptake of the twelve analyzed tissues. Other scientists have shown that fish can accumulate monocyclic aromatic hydrocarbons from chemical mixtures, e.g. crude oil (Roubal, Stranahan and Malins 1978).

It has been suggested that cycloalkanes and other Water Soluble Fraction compounds from petroleum and its products may be more toxic than aromatics or that there is an additive effect with aromatics present (Caldwell, Caldaroni and Mallon 1977). Further research should be conducted to study the interaction and combined effect of these two groups of cyclic compounds and to determine if the additive effects are manifested at the population and community levels.

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AN ANALYSIS OF CANVASBACKS BANDED IN CALIFORNIA¹

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Most canvasbacks, *Aythya valisineria*, of the Pacific Flyway winter in California (about 83%). San Francisco Bay and adjoining San Pablo Bay are the major areas of concentration and hunter kill. Less than 1% of 5,670 canvasbacks banded adjacent to San Pablo Bay were recovered outside the Pacific Flyway. Adult canvasbacks trapped consisted of 69% males ($\pm 1.3\%$, $P < .05$) whereas subadults were 52% males ($\pm 3.7\%$). Little interchange occurs between canvasbacks wintering in northern and southern California. Adult male survival (82%) is significantly higher ($P < .05$) than female (69%).

INTRODUCTION

About half the 290,000 canvasbacks found in North America on January surveys (1960-1971) winter in the Atlantic Flyway, slightly over a fourth in the Pacific Flyway, and the remaining quarter in between, including Mexico. The largest number of canvasbacks (95,000) winter in Chesapeake Bay, and the second largest number (60,000) spend the winter months in the San Francisco Bay area (Bellrose 1976). Geis (1974) stated that California and Maryland are the two major wintering areas in North America.

The 1978 midwinter waterfowl survey on the Pacific Flyway (Bartonek 1979) indicates a canvasback population of about 79,000, a 15% increase over the 10 yr average (1969-1978) and a 7% increase over the 25 yr average (1954-1978). The 1978 count in California was about 65,000, indicating that California winters most canvasbacks on the Pacific Flyway. San Francisco and San Pablo bays are where many of these birds are counted (Table 1).

TABLE 1. Average Number of Canvasbacks Wintering in California and the Pacific Flyway States. *

Year	San Francisco and San Pablo Bays	California †	Pacific Flyway States ‡
1969	31,595	51,375	62,688
1970	28,370	52,335	63,157
1971	23,260	37,124	47,615
1972	25,378	34,573	48,204
1973	31,315	44,942	54,579
1974	8,035	66,857	83,310
1975	19,086	68,468	77,673
1976	26,025	50,330	83,261
1977	22,160	72,155	88,336
1978	22,358	65,490	78,313

* Determined from mid-winter waterfowl inventory conducted by Pacific Flyway states and FWS.

† Includes San Francisco and San Pablo Bays.

‡ Includes California.

¹ A contribution of Federal Aid in Wildlife Restoration Project W-30-R, "Waterfowl Studies". Accepted for publication May 1984.

Deterioration and loss of habitat by pollution and changes in kind and amount of emergent and submergent vegetation, exacerbated by drought, increased predation on breeding grounds, and excessive hunting have collectively resulted in decreased canvasback populations continent-wide from the early 1950's to late 1960's (Stoudt 1970). Because of a decreasing population and a need for information on canvasbacks wintering in California, the California Department of Fish and Game (DFG) and the U.S. Fish and Wildlife Service (FWS) initiated a cooperative trapping and banding program in 1968. The objectives were to obtain information on migration patterns, harvest, and survival rates.

METHODS

The annual midwinter Waterfowl Survey conducted by DFG and FWS show San Pablo Bay as the primary wintering area for canvasbacks in California, and also on the Pacific Flyway. It was therefore chosen as our initial trapping site. However, because of unfavorable conditions caused by mud and tide, the bay was abandoned in favor of a nearby 939 ha salt company evaporation pond which was used by canvasbacks from the bay. This pond borders on State Highway 37, 6.4 km west of Vallejo and is separated from the north shore of San Pablo Bay by the highway and approximately 0.8 km of tidal salt marsh (Figure 1).

The banding period extended each year from about 1 February to 15 March when trapping success declined. Traps were 3 m by 6 m and approximately 1.5 m high with a funnel type entrance on one end and a holding or banding pen on the other. They were set in about 0.5 m of water over a firm bottom and were baited with corn or rice with approximately equal success. The traps were checked daily, the birds banded, and released after sex and age were recorded.

RESULTS AND DISCUSSION

Between 1968 and 1978, 5670 canvasbacks were captured, banded, and released. Through the 1979-80 hunting season, 783 band recoveries were obtained.

Seventy percent of the canvasbacks banded at the salt pond were recovered from the San Francisco Bay-Delta area including San Pablo Bay (Table 2). The Sacramento Valley was second with approximately 10% of the recoveries, and areas of lesser importance in California account for another 10%. The remaining 10% was recovered elsewhere in the Pacific Flyway. Less than 1% was recovered outside the Pacific Flyway, suggesting that the west coast canvasback population is separate from eastern North America. The distribution of average annual harvest (1971-1980) of canvasbacks as determined from the Waterfowl Parts Survey (Carney, Sorensen, and Martin 1983) indicate that approximately 60% of the harvest occurs in the San Francisco Bay-Delta-Sacramento Valley area, and about one-half of this occurs in the San Pablo Bay area. Bands recovered in California from canvasbacks banded in other states and provinces show 50% of the recoveries coming from the San Francisco Bay-Delta area (Table 3).

San Pablo Bay and the adjoining Napa Marsh accounted for approximately 62% of the band recoveries (Table 4). However, this is believed to be partially biased because banding occurred only in this area. Nevertheless, in a prior study (unpublished data) recoveries from canvasbacks banded a few miles from San Francisco Bay at Lake Merritt, in downtown Oakland, also indicate the San Pablo Bay-Napa Marsh to be an important recovery area in California (Table 5).

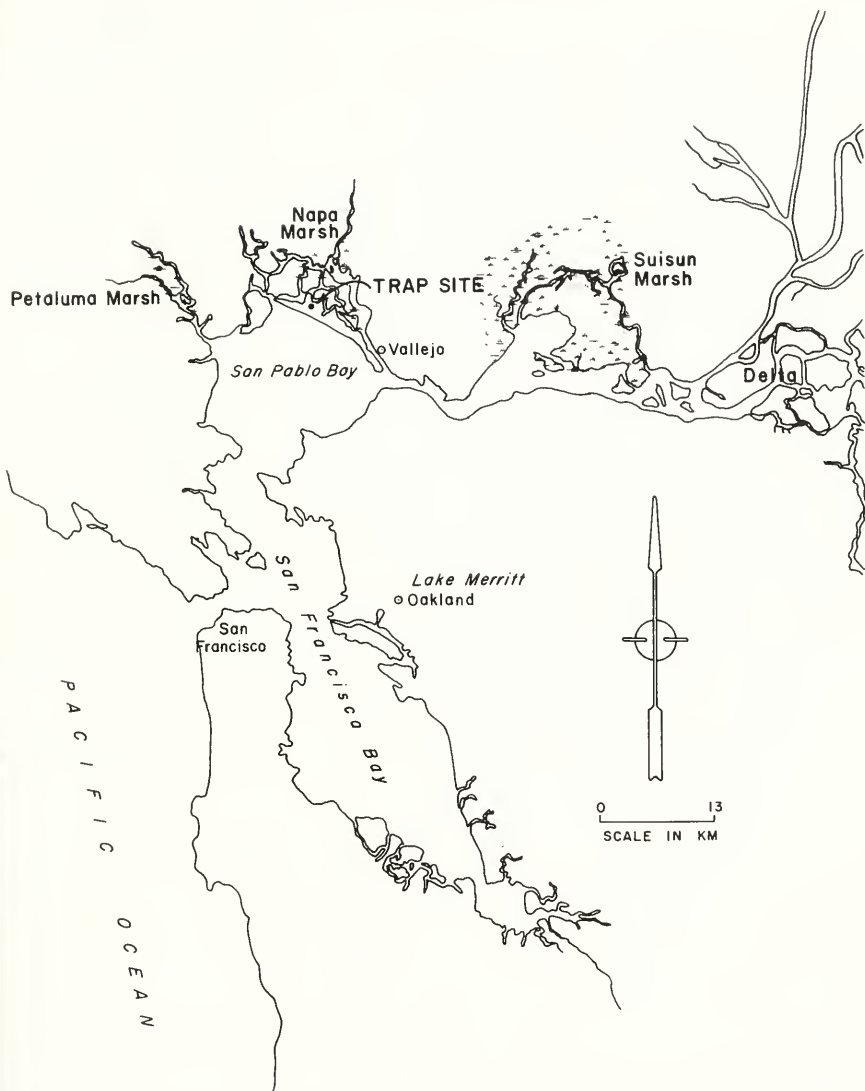


FIGURE 1. Location of trap site and harvest areas within the San Francisco Bay-Delta recovery area.

In the winter, during periods of heavy run-off into the Sacramento River, the Yolo and Sutter Bypasses in the Sacramento Valley are flooded to alleviate damage to the river levees. These large flooded areas of farm land (mostly rice) attract numerous waterfowl, including canvasbacks, and become important band recovery areas.

This study's recoveries show that canvasbacks from breeding grounds in Alaska and Canada winter in California. Recoveries from Alaska are scarce (one), but recoveries from the Washington and Oregon coast suggest they come down the coast. Recoveries from canvasbacks banded in Alaska, although few, suggest the principal migration route extends through southern British Columbia, Washington, Oregon to northern California (Stewart, Geis, and Evans 1958;

Bellrose 1976). It appears that canvasbacks banded at the salt pond and recovered in south-central Oregon (14) could have come from Alaska or Canada. Banded canvasbacks recovered in northern Utah could represent local breeding populations or breeding areas farther north and east including Alberta, Idaho, Wyoming and North Dakota. Stewart *et al.* (1958) reported that about one-half of the recoveries on the wintering grounds of summer banded canvasbacks in the short-grass prairies and aspen parklands of southern Alberta and the Caribou Parklands of British Columbia were from areas near the Pacific Coast. The greatest concentration occurred in the San Francisco Bay-Delta area. South Alberta is the most important breeding area for canvasbacks wintering in California.

Bands recovered in California indicate that birds banded in western Nevada are strongly oriented to northern California, especially the San Francisco Bay-Delta where 57% of the bands were recovered (Table 3). Canvasbacks banded in eastern Nevada were more oriented to southern California although 41% of the bands were also recovered in the San Francisco Bay-Delta area. None of the canvasbacks banded in western Nevada were recovered in southern California, and only 2% of the salt pond birds were recovered there. Previous studies of lesser snow geese, *Chen caerulescens*, (Rienecker 1965) and American wigeon, *Anas americana*, (Rienecker 1976) showed that birds wintering in southern California are from a different population than those wintering in northern California. These studies indicate that both populations can originate from the same general breeding areas in Canada, but birds wintering in southern California usually nest in areas east of those wintering in northern California.

TABLE 2. Indirect Winter Banding Recovery Summary of 5,670 Canvasbacks Banded Adjacent to San Pablo Bay 1968-1978 and Recovered Through the 1979-80 Hunting Season.

Recovery Area	Bands Recovered					
	Male		Female		Total	
	Number	Percent	Number	Percent	Number	Percent
Calif. (northeast)	15	2.6	6	2.7	21	2.7
Calif. (north coast)	9	1.5	1	0.5	10	1.3
Calif. (Sacto. Valley)	59	10.4	20	9.2	79	10.1
Calif. (S.F. Bay-Delta)	389	68.6	160	74.0	549	70.1
Calif. (south coast)	8	1.4	3	1.4	11	1.4
Calif. (San Joaquin Valley)	24	4.2	7	3.2	31	4.0
Calif. (Inyo-Mono)	1	0.2	-	-	1	0.1
Calif. (Imperial Valley)	4	0.7	1	0.5	5	0.6
Alaska			1	0.5	1	0.1
Alberta	13	2.3	2	0.9	15	1.9
Saskatchewan	1	0.2	-	-	1	0.1
Washington (coast)	1	0.2	-	-	1	0.1
Oregon (coast)	9	1.5	-	-	9	1.2
Oregon (south-central)	10	1.8	4	1.9	14	1.8
Idaho (south)	4	0.7	-	-	4	0.5
Idaho (east)	2	0.4	1	0.5	3	0.4
Utah (north)	9	1.5	6	2.7	15	1.9
Nevada (west)	3	0.5	1	0.5	4	0.5
Nevada (east)	1	0.2	1	0.5	2	0.3
Nevada (south)	1	0.2	-	-	1	0.1
North Dakota	-	-	1	0.5	1	0.1
Wyoming	1	0.2	-	-	1	0.1
Minnesota	1	0.2	-	-	1	0.1
Texas	1	0.2	1	0.5	2	0.3
Total	567	99.9	216	100.0	783	99.9

The unbalanced sex ratio in favor of canvasback males has been reported numerous times (Hochbaum 1944, Geis 1959, Nichols and Haramis 1980a). Canvasbacks wintering in California are no exception. The sex ratio of the 4,967 adult canvasbacks banded on the salt pond was 69% males ($\pm 1.3\%$, $P < .05$) (Tables 6 and 7). This compares to canvasbacks in Michigan with 79% males, New York with 78% males, and Louisiana with 67% males (Nichols and Haramis 1980a). Geis (1959) stated that although the causes of the unbalanced sex ratio are complicated, it can be concluded that females ordinarily have a higher rate of mortality than males during both the breeding season and the hunting season. Data from New York canvasback bandings strongly suggest substantial female mortality from causes other than hunting (DeGraff, Foley, and Benson 1961). In a study conducted in Manitoba, Olson (1965) reported that the disproportionate sex ratio of canvasbacks appears to be largely the result of differential vulnerability to hunting. He further stated that it appears that females are killed in excess of males until the population contains 60–65% males and then males are killed in greater numbers, thus female vulnerability is balanced by the numerical abundance of males. The sex ratio of the 703 subadults trapped on the salt pond after their first hunting season (Table 6), was 52% males ($\pm 3.7\%$, $P < .05$) suggesting that the harvest rate for both sexes was similar. Thus, the high mortality rate for females resulting in the unbalanced sex ratio most likely occurs after the first year of life.

TABLE 3. Band Recoveries From Canvasbacks Banded Outside of California and Recovered in California 1971–1979.

Banding areas	California recovery areas							Total
	North-eastern	North coast	Sacramento Valley	S.F. Bay Delta	San Joaquin Valley	South coast	Imperial Valley	
Alaska			1(10.0) *	8(80.0)			1(10.0)	10
Yukon	1(100.0)							1
Alberta	1(6.7)	2(13.3)	2(13.3)	8(53.3)	1(6.7)	1(6.7)		15
Saskatchewan	1(10.0)		1(10.0)	5(50.0)	1(10.1)		2(20.0)	10
Manitoba		1(33.3)				1(33.3)	1(33.3)	3
Minnesota							1(100.0)	1
Illinois		2(33.3)		1(16.7)	3(50.0)			6
Maryland			2(20.0)	7(70.0)	1(10.0)			10
New York	1(25.0)	1(25.0)	1(25.0)	1(25.0)				4
Nevada-west	3(10.0)	2(6.7)	6(20.0)	17(56.7)	2(6.7)			30
Nevada-east		1(3.7)	2(7.4)	11(40.7)	5(18.5)	2(7.4)	6(22.2)	27
Total	7(6.0)	9(7.7)	15(12.8)	58(49.6)	13(11.1)	4(3.4)	11(9.4)	117

* Percent

TABLE 4. Canvasback Band Recovery Areas Within the San Francisco Bay-Delta, California.

Area	Number of recoveries	Percent
San Pablo Bay	249	45.3
Napa Marsh	94	17.1
San Francisco Bay	73	13.3
Suisun Marsh	48	8.7
Petaluma Marsh	35	6.4
Delta	24	4.4
Yolo Bypass	10	1.8
Tomales Bay	8	1.5
Miscellaneous	8	1.5
Total	549	100.0

TABLE 5. Indirect Winter Banding Recovery Summary of Canvasbacks Banded at Lake Merritt, California 1971-1979.

Alberta	3 (1.9) *
Saskatchewan.....	2 (1.3)
Colorado.....	2 (1.3)
New Mexico	1 (0.6)
Mexico (west coast)	1 (0.6)
Oregon	2 (1.3)
Utah	5 (3.2)
Nevada	2 (1.3)
Calif. (northeast).....	4 (2.5)
Calif. (north coast)	1 (0.6)
Calif. (Sacto. Valley)	12 (7.6)
Calif. (S.F. Bay).....	61 (38.6)
Calif. (San Pablo Bay)	55 (34.8)
Calif. (south coast).....	1 (0.6)
Calif. (San Joaquin Valley)	6 (3.8)
Total	158 (100.0)

* Percent

Differential migration resulting in differences in the distribution of harvest for different sexes and ages of canvasbacks has been well documented (Hochbaum 1944; Stewart *et al.* 1958; Geis 1974; Nichols and Haramis 1980a). In other flyways adult males migrate south from the breeding grounds before adult females. Thus, more adult females than males are shot on the breeding grounds or enroute south to the wintering grounds. Most of the adult male harvest occurs late in the season. For example, considering canvasbacks banded in the mid-Atlantic states, 43% of the females and 71% of the males harvested were shot on the wintering grounds (Stewart *et al.* 1958). In this study, of canvasbacks banded in California, 89% of the females and 87% of the males harvested were shot on wintering areas in California (Table 2). Times of harvest were also essentially the same for both sexes (Table 8). Thus there is no indication that a differential migration of the sexes occurs on the Pacific Flyway of the magnitude noted on the eastern flyways. Stewart *et al.* (1958) suggested that the pattern of hunting kill of wintering canvasbacks banded in California differed from that of other wintering populations because the kill was more concentrated near the wintering areas where the banding was done. They also stated that the California population apparently migrated through areas of light hunting pressure while other populations are shot more heavily during migration and on the breeding grounds.

Canvasbacks have a strong homing instinct and return to the same breeding area each year (Bellrose 1976). If the number of birds retrapped on the original trap site one or more years later can be used as a criterion, then homing instinct to the same wintering area also appears strong (Table 6, mean = 19%, range = 10-35%). Nichols and Haramis (1980a) reported that both male and female canvasbacks seemed to exhibit comparable degrees of fidelity to general wintering grounds. Serie, Trauger, and Sharp (1983) stated that canvasbacks staging on the upper Mississippi River exhibited strong fidelity to wintering areas.

TABLE 6. Age, Sex and Retraps of Canvasbacks Banded on a Salt Company Pond Adjacent to San Pablo Bay, Calif. 1968-1978.

	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	Total
After second year male	523	840	169	171	138	233	244	200	84	315	224	3,411
Second year male	28	14	91	30	14	53	44	49	24	11	6	364
After second year female.....	247	348	94	117	151	119	109	45	117	121	93	1,556
Second year female	54	11	83	31	30	19	28	33	21	22	7	339
Total	852	1,208	437	349	333	694	425	327	246	469	330	5,670
Retraps *		168	106	71	117	76	140	121	135	124	89	1,147
Retraps—% of total caught		12.2	19.5	16.9	26.0	9.9	24.8	27.0	35.4	20.9	21.2	19.2

* Canvasbacks that were banded in prior years on the same pond.

TABLE 7. Sex Ratios of Adult Canvasbacks Banded Adjacent to San Pablo Bay, California, 1968-1978.

Year	Males	Females	Males:Females
1968.....	523	247	2.12:1
1969.....	840	343	2.45:1
1970.....	169	94	1.80:1
1971.....	171	117	1.45:1
1972.....	138	151	0.91:1
1973.....	503	119	4.23:1
1974.....	244	109	2.24:1
1975.....	200	45	4.44:1
1976.....	84	117	0.72:1
1977.....	315	121	2.69:1
1978.....	224	93	2.41:1
Total	3,411	1,556	2.41:1 or 69% males

TABLE 8. Harvest Dates of Banded Canvasbacks in California.

Bands Recovered						
Male			Female			
Harvest periods	Number	%		Number	%	
Oct. 1-10	1	0.2	2.3	-	-	1.2
11-20	1	0.2		1	0.6	
21-31	8	1.9		1	0.6	
Nov. 1-10	7	1.6	15.2	9	5.2	18.5
11-20.....*	26	6.1		8	4.6	
21-30.....	32	7.5		15	8.7	
Dec. 1-10.....	48	11.2	41.0	15	8.7	43.0
11-20.....	51	11.9		32	18.6	
21-31.....	77	17.9		27	15.7	
Jan. 1-10	68	15.9	41.5	34	19.8	37.3
11-20.....	97	22.6		29	16.9	
21-31 *	13	3.0		1	0.6	
Total	429	100.0		172	100.0	

* Hunting season usually ended during or prior to this period.

Some canvasbacks (5-10%) became "trap happy" and were caught numerous times. At the beginning of the trapping period most appeared to be in good body condition. However, by the end of the trapping season the more persistent trap happy birds were observed to have lost considerable body weight compared to newly trapped birds. The cause of this weight loss is unknown, but it could have been caused by capture stress. Another possibility was that bait was not of sufficient nutritional value or quantity to maintain body weight on birds that fed extensively on bait for up to six weeks. No birds were weighed during this study. In future diving duck banding studies, however, weights should be taken to determine weight loss and how to avoid it. A significant weight loss prior to spring migration could affect the birds ability to migrate and reproduce. Lipid reserves carried to the breeding grounds contribute substantially to the needs of mallard pairs during reproduction (Krapu 1981).

Using data obtained from canvasbacks banded on the salt pond, Nichols and Haramis (1980b) determined male survival to be 81.8%, and female 69.0%. The difference is significant ($P < .05$). This compares with 75.2% and 56.2% for canvasbacks banded in the three mid-Atlantic states of Delaware, Maryland and

Virginia, and 72.6% and 56.1% for canvasbacks banded in New York. Although these comparisons were not always from birds recovered in the same years, it does suggest that canvasbacks wintering in California have a higher survival rate than birds on the other two areas.

The California population of canvasbacks is separate from that of the east coast of North America and thus should continue to be managed separately.

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THE SURVIVAL AND MORTALITY OF SEEDED AND NATIVE RED ABALONES, *HALIOTIS RUFESCENS*, ON THE PALOS VERDES PENINSULA¹

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A one year experiment to test the feasibility of using hatchery-reared juvenile red abalones, *Haliotis rufescens*, to enhance depleted native populations was conducted off the Palos Verdes Peninsula in Los Angeles County. Behavior, growth, survival and mortality patterns for two groups of seed averaging 45 and 71 mm at the time of planting were compared with native abalones at the site. Predators and scavengers were collected at the beginning of the experiment to ease pressure on the seed; predator collections were continued at monthly intervals throughout the year. After one year the seeding site was destructively sampled. Seed growth averaged 30 mm per year. Survival as based on the recovery of live seed was about 1%. Seed mortality, estimated from shell collections, was 43%, suggesting that a large proportion of the unaccounted for animals moved away. Intense predation pressure, particularly by octopuses, appears to be limiting both the success of seeding experiments and the recovery of native populations.

INTRODUCTION

The Japanese pioneered the seeding of hatchery-reared juvenile abalones into wild populations to enhance fishable stocks (Ino 1966, Kan-no 1975, Inoue 1976). In 1976, 5,255,000 juvenile abalones were produced by 29 hatcheries throughout Japan for release to the natural environment (T. Seki, pers. commun.). Inoue (1976) reported that the survival rate of hatchery-reared abalones one year after planting increased with the size of seed and leveled off at about 70% survival for 70 mm and larger seed. Because such large seed are very expensive to produce however, the Japanese release most hatchery-reared abalones at a size of 20 to 30 mm (Mottet 1978). Once fishery cooperatives plant the abalones on the designated growing grounds, the seed are left on their own to grow to market size (Shaw 1982).

In California, abalones are preyed upon by a wide variety of predators including man (Cox 1962) and are highly preferred by many of these predators (Ebert 1968, Ambrose 1982b, Tegner and Butler unpubl. data). Hines and Pearse (1982) have argued that abalone populations persist in the face of intense predation pressure through high rates of juvenile recruitment and growth.

The University of California Sea Grant College Program and California Department of Fish and Game have been working together to investigate the feasibility of using seeding to enhance abalone populations in depleted areas of southern California. After preliminary data suggested that survival of 20 to 30 mm seed was very poor, a small-scale experiment using large seed was initiated on the Palos Verdes Peninsula near Los Angeles. A major advantage of working with larger, thicker-shelled seed is that predators rarely destroy such shells completely when they consume the soft tissues and damage to the shell can often be

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attributed to a specific predator. Monthly searches were made for predators and shells. Here we discuss the mortality patterns and one year survival rate for two sizes of seed and compare the results with the native abalone in the same area. The results suggest that intense predation is limiting seeding success and the recovery of native populations on the Palos Verdes Peninsula.

MATERIALS AND METHODS

The study site was located in a kelp forest south of Palos Verdes Point (lat. 33°46.2'N, long. 118°25.5'W) at a depth of 10 m. The habitat includes reef structures with ledges and crevices and boulder-filled sand channels. Drift kelp was abundant during the experiment.

A 25 x 25 m site was selected and the boundaries were permanently marked with lead line. Transects were used to estimate the densities of native abalones, predators and scavengers and to analyze the physical habitat. Emergent (visible to a diver without turning rocks, generally large adults) abalones and predators were counted in 5 m² segments along 25 x 2 m transects; five randomly chosen 1 m² quadrats along each line were used to search for cryptic abalones, predators and scavengers. The physical habitat along the transect was described (e.g. sand, turnable boulder, nonturnable boulder or reef, or pavement) to estimate the percent suitable for juvenile abalones.

Red abalones, *Haliotis rufescens*, were shipped from central California in plastic bags containing a sponge saturated with seawater and filled with oxygen. The bags were packed in styrofoam ice chests; insulation shielded the abalones from direct contact with the ice. After a maximum of 12 hours in transit, the ice chests were opened onboard the KELP BASS and the abalones allowed to warm before being placed in mesh bags and hung in running seawater. Thermal stress was a concern since the animals had been cultured at 10–12° C and the surface temperature at Palos Verdes was an unseasonal 19° C. Animals placed on their backs in seawater immediately after unpacking turned over rapidly and attached; there was no behavioral evidence of thermal shock. The next morning the abalones had attached to each other and appeared to be healthy. The abalones were acclimatized onboard ship for 36 hours. Bottom temperatures at the experimental site varied between 16 and 18° C during the early stages of planting and dropped to 13.5° C on 27 May 1981.

The seed came from two hatcheries. Four hundred ninety-nine abalones from California Marine Associates (CMA) averaged 71 mm (range 60 to 80 mm) and had thick, reddish-grey shells with some erosion near the spire. One hundred seventy-five seed from the Department of Fish and Game's Granite Canyon Laboratory (GCL) averaged 45 mm (range 40–57 mm) with aquamarine-colored shells of normal thickness for their size and minimal spire erosion. A Dremel-Moto Tool equipped with a grinding disc was used to grind a single V-shaped notch about 5 mm deep into the growing edge of the shell of the CMA seed just posterior to the respiratory pore line and two notches into the shells of the MCL seed (Figure 1). Previous work has shown that if the mantle is pushed away from the grinder, notching does not appear to injure the animal and is filled in within a few days. The repaired notch remains visible and is an unambiguous indicator of both the origin of the animal and its size at planting (Figure 1).



FIGURE 1. Shell notches remain visible and are an unambiguous indication of seed size at planting. Left. This single-notched CMA abalone measured 69 mm at planting and had grown 40 mm when the shell was recovered 8.5 months later. Right. This double-notched MCL abalone was 50 mm at planting and 72 mm when it was found a year later.

The abalones were individually planted into protective habitat such as boulder piles, crevices or the undersides of flat rocks. Rock surfaces were cleaned with steel brushes to facilitate attachment. One hundred sixty abalones were seeded into mapped locations, chosen on the basis that they could be searched completely without harming the abalones, to follow seed dispersal and predator attraction on subsequent days. Planting was begun on 14 and 15 May 1981 and then curtailed due to large swells. The remaining abalones (50% of the CMA and 5% of the MCL seed) were kept in aquaria at Scripps Institution of Oceanography until they could be planted on 26 and 27 May 1981. The planting density of seeded abalones was 1.08 per m².

Our previous studies (Tegner and Butler unpub. data) indicated that even carefully handled abalones attract scavengers and predators when they are separated from each other and planted into natural habitats. Scavenging sea stars, mainly *Pisaster giganteus* at Palos Verdes, and Kellet's whelk, *Kellettia kellettii*, will attack stressed but living abalones, but after a few days the abalones adapt and are no longer susceptible to these predators. Predators which continue to consume abalones include *Octopus* spp.; the sea star, *Astrometis sertulifera*; the crabs, *Loxorhynchus grandis* and *Cancer* spp.; and the spiny lobster, *Panulirus interruptus*. Scavengers and predators were collected during the pre- and post-planting surveys as well as during seeding and predators were collected during the entire year of the experiment. All encountered abalone shells, both seeded and native, were collected during and soon after planting and at approxi-

mately monthly intervals thereafter. The condition of each shell was noted for indication of predator-type and any growth was measured. Haphazard searches were made to monitor live seed with minimal disruption of the habitat.

One year after seeding, the entire 625 m² site was destructively sampled. Selected areas outside the boundaries were also destructively sampled in May and June of 1982 and larger areas were searched for emergent abalones and shells on several visits over the next five months.

RESULTS

Fourteen transects were run in and adjacent to the seeding site before planting. No emergent abalones were found in 700 m². The average density ($\pm$ S.E.) of cryptic native red abalones was 0.17 ± 0.12 per square metre for 70 m² sampled. Because about 40% of the planting area was unsuitable for juveniles, we estimate that there were about 64 (95% confidence interval: 19–109) native red abalones in the study area at the beginning of the experiment.

The nocturnal *K. kelletii* are also best enumerated by destructively sampled quadrats. By day most are generally found under rocks, in crevices or, as we have observed in aquaria after the whelks have had a meal, they will bury themselves in the sediment. Their average density ($\pm$ S.E.) was $1.46 \pm .21$ per square metre. The other important scavenger on stressed abalones, *Pisaster giganteus*, was also abundant ($0.96 \pm .11$ per 5 m²). Predators present in low numbers in the planting site included *A. sertulifera*, *Octopus* spp., *L. grandis* and *P. interruptus* (Table 1).

Eighty abalones of each seed type were planted into mapped locations for observation on subsequent days. Each location and its surrounding area was carefully searched for possible predators and scavengers; this search included digging a few centimeters into the sand for buried *Kelletia*. These animals were collected for transplantation several kilometers outside of the study area, or in the case of an elusive octopus, the site was not used. Nevertheless predators were attracted. One large octopus was caught crawling into a plant site during daylight about 15 minutes after some abalones were planted. The next day a large octopus was caught apparently just beginning to eat two CMA seed in one of the sites. A total of 40 *Kelletia* was found in the 22 plant sites one day after planting; one CMA mortality was being consumed by 12 of the whelks. One additional shell was found with no evidence of the predator. Of 79 mapped abalones, 80% were found alive the next day near their plant site, two shells represented less than 3% mortality and 18% could not be accounted for and presumably had moved away. One native red abalone had joined a clump of seed.

The mapped seed were reobserved 10 or 11 days after planting when the seas calmed. Of the 160 originally mapped, 39% were seen live, shells represented 13% mortality and 48% were unaccounted for. Evidence for movement includes one CMA seed which had joined a group of MCL abalones in a mapped site. The smaller MCL seed apparently had a greater tendency to move away from their plant sites. One day after planting 13% more MCL seed than CMA seed were unaccounted for but the difference was not significant (G test, $G = 0.8$, $P > 0.1$). By 11 or 12 days this difference was 21% and significant (G test, $G = 7.34$, $P < .01$). Similar mapping studies with smaller red and green (*H. fulgens*) abalone seed offer further evidence that smaller abalones are more

TABLE 1. Predator and Scavenger Densities From Preplant Transects and the Numbers Collected During and After Planting.

Predator/ Scavenger	Density ($\bar{x} \pm S.E.$)	Removals 5/12-15	5/26-27	6/19	8/3	9/12	10/1	10/21	12/11	2/4	2/25	4/7	5/21	Total collected
<i>Kellelia</i>	1.46 $\pm$.21													
<i>kellelii</i>	per m ²	550	916	290	241	255	*	*	*	*	*	*	*	2,552
<i>Pisaster</i>	0.96 $\pm$.11													
<i>giganteus</i>	per 5 m ²	74	138	15	75	48	*	*	*	*	*	*	*	350
<i>Astronotus</i>														
<i>serotifera</i>	3/70 m ²	3	10	1	2	4	0	0	0	0	0	1	11	32
<i>Octopus</i> spp.	2/70 m ²	3	11	2+1*	4	0	3	1+1*	2	3+1*	3	1+1*	7+2*	40
<i>Loxodhynchus</i>														
<i>grandis</i>	2/700 m ²	1	6	2	1	0	0	0	0	0	0	0	1	11
<i>Panulirus</i>														
<i>interruptus</i>	1/700 m ²	0	1	4+1*	1*	0	0	1+2*	0	2	4	1*	0	12
<i>Cancer</i> spp.	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Effort:	Day:	45	15	-	4	3	2	-	4	4	4	3	59	143
(# dives)	Night:	-	3	6	-	-	-	3	-	-	-	-	-	12

* Observed only.

mobile. Whereas we were able to account for 55% of the CMA seed and 36% of the MCL seed after 12 days, we were only able to locate 23% of 21 mm green seed after 7 days and 19% of 13 mm red seed after 25 days (Tegner and Butler unpublished data).

Some of the larger CMA abalones displayed the normal reflex reaction, drawing their shell tightly to the substrate in response to disturbance, as soon as one day after planting. This reaction is important in reducing susceptibility to predation; e.g., an octopus would be more likely to have to drill a tightly attached abalone instead of simply pulling it off. None of the shells found one day after the mapped abalones were planted was drilled; 35% of those found 11 or 12 days later were drilled.

The scavenger and predator collections are summarized in Table 1. While the onset of bad weather hampered collections in early May, the large increase in numbers of every species in late May with less collecting effort makes it apparent that scavengers and predators were being attracted to the seeding site. This was illustrated by the fresh remains of a *Loxorhynchus*; we collected several batches of *Kelletia* off the carapace over a few days. While these efforts probably reduced the pressure on the seed during acclimation, they did not eliminate it. One seed was rescued from an octopus on one day and found being consumed by a *Kelletia* the next.

By late May, abalones planted in early May appeared to have adapted. Many were observed feeding and with fully spread mantles. Some of the dead seed found in late May had filled in their notches indicating that they had grown before they were preyed upon. By June some of the plant sites were no longer occupied but there were several observations of six to nine CMA seed under individual rocks, suggesting either gregarious behavior since they were not planted at those densities or agreement on preferred habitat. Increasing proportions of the mortalities found at each visit exhibited growth before death and the average growth increment progressively increased. By June, some of the shells were found outside the perimeter of the planting area. Decreasing numbers of live seed were observed during haphazard rock rolling as the year progressed.

Scavenger collections were stopped after September but we continued to take predators (Table 1). A large lobster was observed on its side, attempting to pry a CMA seed off the underside of a rock on a night dive. A large octopus was pulled away from a CMA abalone during the day in October and three large octopuses were found in December, each within 50 cm of a planted abalone. Octopuses were caught on every visit except September. Typically seasonal, *Loxorhynchus* are found in kelp forests off Palos Verdes during the late spring and summer. Broken plant shells were only found during this period. *Cancer* spp. are rare in this area. The bat ray, *Myliobatis californica*, an important predator of larger, more exposed abalones in nearby shallow (< 7 m) waters, was observed at this site but we have no evidence of any bat ray predation during this experiment. Similarly a few cabezon, *Scorpaenichthys marmoratus*, fish which ingest abalones whole, were also observed but there were no shells found with the acid-etching characteristic of this predator (Hines and Pearse 1982, Tegner and Butler unpublished data).

After one year the entire 625 m² seeding site was destructively sampled to search for live abalones and cryptic shells. Live seed recoveries are summarized in Table 2. Only eight seed (out of 674 planted) were found within the site. All

were nonemergent, found under turnable boulders, in urchin depressions or in crevices. Growth averaged 30 mm for both seed types although there was a two-fold variation in growth rate among the six CMA abalones. To search for migrants, a 2 m swath around the entire perimeter, a 6 m wide swath along the southern perimeter and a 6×25 m swath 10 m west of the western boundary were also destructively sampled. One live CMA was found by chance 10 m to the south of the seeding site. Less intensive searches produced seed shells up to 100 m away.

TABLE 2. Seeded Abalones Recovered Within the 625 m² Planting Site.

Type of seed	Number recovered live	Recovery rate	Average size at planting (mm)	Average growth (mm)	Growth range (mm)
CMA.....	6	1.2%	71	30	20-41
MCL.....	2	1.1%	45	31.5	31-32

The destructive sampling located 23 plant shells within the seeding site; 25 others were found in the perimeter searches. These included shells which did not grow after planting and presumably died very soon after the start of the experiment. The one year mortality estimates based on collections of shells throughout the year are shown in Table 3. Recoveries of 211 CMA shells represent 42% mortality and 60 MCL shells correspond to 34% mortality. (Extensive perimeter searches over the next five months located an additional 22 CMA and 1 MCL shells, raising the known mortalities to 47% and 35%, respectively.) In contrast the one year native red abalone mortality rate, as based on the population estimate at the start of the experiment, was 88%. Growth analysis of all the seeded shells (through 17 months, Figure 2) indicates that almost half of the mortalities of each seed type (21% of all seed planted) did not grow before death and can be considered planting mortalities. As the animals adapted and grew, their apparent mortality declined considerably.

Seeding mortality is also evident in the classification of shells by predator type (Table 3). Abalones stressed by transplanting are more susceptible to simply being pulled off the substrate so a predator may not be forced to drill or gnaw at the edges of the shell. Thus much larger proportions of the seeded than the native shells show no evidence of a predator. Octopuses do not drill all their prey (Ambrose 1982b) so the data in Table 3 underestimate their importance to abalone populations at Palos Verdes. About one third of the shells had the chipped edges and scratches characteristic of crustacean predation. A small number of shells had the round drill holes characteristic of *Ceratostoma nuttali* drills (Tegner and Butler unpublished data). No seasonality was apparent for any of the predation types.

The size-frequency distributions of live native red abalones sampled by transects in 1981 and collected from the entire 625 m² seeding site in 1982 and native shells collected within the seeding site over the 12 month period of the experiment are illustrated in Figure 3. The size-frequency distributions of the live abalones and of the shells are all significantly different (Kolmogorov-Smirnov tests, $P < .05$). The mean size of the live animals was 28 mm in 1981 and 38 mm in 1982; the mean size of the shells collected over the course of the year was 45 mm. However, we have no evidence that the native red abalone density changed; the 46 abalones recovered are well within the 95% confidence limits

for the 1981 estimate. Juvenile red abalones at Palos Verdes grow about 30 mm per year (Tegner and Butler unpublished data). Both the growth rate and high mortality rate of native red abalones in this experiment indicate that growth of the existing animals cannot account for the change in the size frequency distribution of the live animals from 1981 to 1982. As we have no evidence that the density changed, there must have been high recruitment to offset the mortality. The larger mean size of the shells suggests differential mortality of larger abalones but aquarium observations indicate that smaller abalone shells are more likely to be ground into unrecognizable fragments (Tegner and Butler unpublished data).

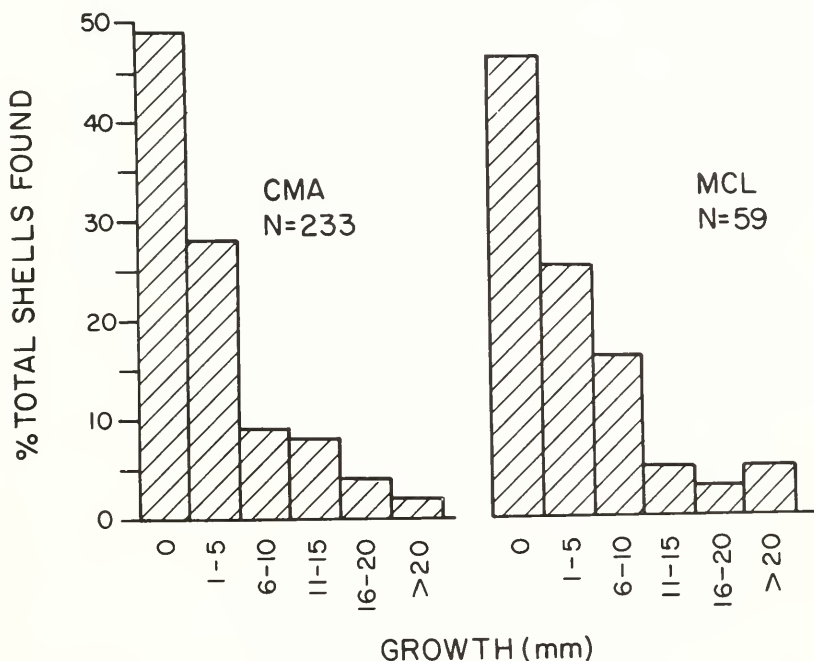


FIGURE 2. Growth analysis of all seed shells recovered through October, 1982.

DISCUSSION

The one year survival rate of hatchery-reared red abalones, based on recovery of live animals within the 625 m² seeding site and 450 m² of surrounding habitat, was about one percent for both seed size groups. Two lines of evidence suggest that these results are not an adequate evaluation of the experiment. First, mortality estimates based on the collected shells account for less than half of the planted animals. How good are mortality estimates made in this manner? Hines and Pearse (1982) found that marked abalone shells dispersed only 2 to 3 m in three months with no net directionality. They concluded that estimates of empty shell production were not biased by net transport of shells out of their study area. We observed the remains of a *Loxorhynchus* in the same location at the Palos Verdes Point site for at least 10 weeks. Schmitt and colleagues (Tegner *et al.*

TABLE 3. Analysis of Seeded and Native Red Abalone Mortality For May 1981–May 1982. Native Shells Were Collected Only Inside the 625 m² Seeding Site; Seed Abalones Were Also Collected From Outside the Site.

Type of abalone	Number at start of the experiment	Average size at start of experiment (mm)	Total number shells collected	Percent mortality	Percent shells with octopus drills	Percent shells other drills	Percent shells with chipped edges	Percent shells with no damage
CMA.....	499	71	211	42	32	0.5	35.5	32
MCL.....	175	45	58	33	33	1.5	31	34.5
Native.....	64 *	28	56	88	38	2	39	21

* Estimate (see text for details)

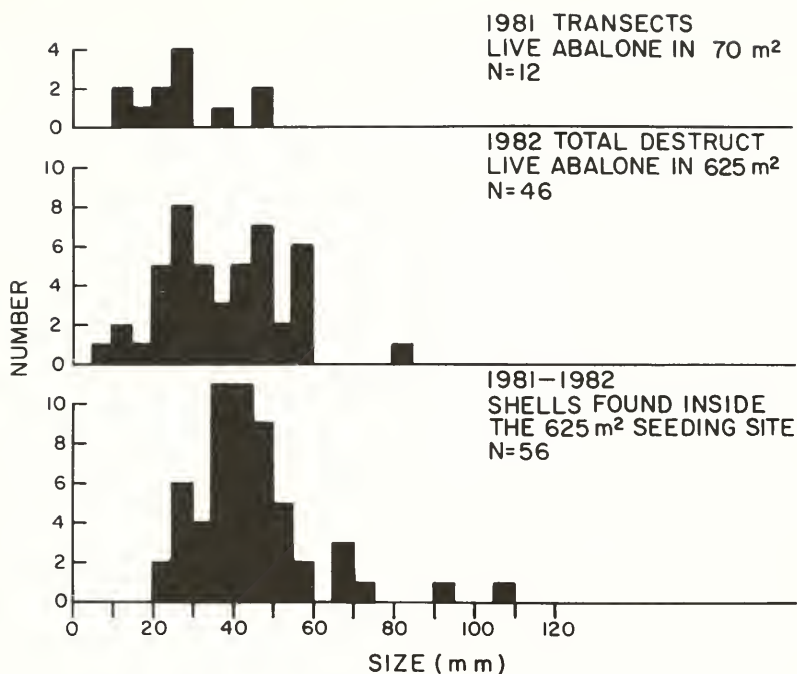


FIGURE 3. Size-frequency distributions of live native red abalones found in the preplant transects in 1981 (top) and during the total destruct of the 625 m² seeding site in 1982 (center), and of the native red abalone shells found within the seeding site during the 12 month experiment (bottom).

1981) planted 1194 marked shells ranging from 13 to 42 mm in the same manner as live seed and recovered 71% of the shells within four months without destructive sampling. Only 8% of the shells found by the end of the twelve month experiment at Palos Verdes Point were recovered by destructive sampling. Even if abalones are consumed in a cryptic location such as an octopus midden, most appear to eventually flush out into the open. Some shells found in the destructive search showed no growth and presumably died close to the time of planting, thus the shells do last. Finally we have little evidence that predation fragments shells of this size beyond recognition; only 5% of the 294 shells recovered were broken into small pieces. Similarly, minimal activity by encrusting organisms did not alter shells beyond recognition. While a few shells doubtlessly were not recovered, given the frequency of our visits (Table 1) and the above characteristics of abalone shells, we believe that collection of shells provided a reasonably good estimate of seed mortality.

Second, we have evidence that live seed dispersed well beyond the study site. There was a progressive decrease in the number of live seed observed in qualitative haphazard searches of the site. We found 126 live seed in June of 1981, 70 in August, 44 in October and 9 in February 1982. Twenty six percent of the shells were recovered in all directions outside of the site. The lack of directionality is

more consistent with random dispersal of live animals than shell transport by prevailing seas. Octopuses and cabezon are the only predators likely to transport their prey to another location. Cabezon, generally found in shallower waters at Palos Verdes, were only observed on one occasion at this site. Ambrose (1982 b) reports that although *O. bimaculatus* is capable of foraging excursions of 20 m or more from its shelter, most foraging is concentrated in a smaller area. Thus, we conclude that transport by predators was probably not important. Finally, one live CMA abalone was found 10 m away from the site and shells were found at least 100 m away. All of the live seed recovered were cryptic, not visible without disrupting the substrate. Because the costs of destructively sampling an area 100 m in radius are prohibitive, a final analysis of seeding success may be possible only once the abalones grow into an emergent size class.

A major concern for enhancement programs is determining the size of seed which optimizes both survival and production cost. The poor recovery rates obtained in this experiment show no difference in survival between seed averaging 45 and 71 mm (Table 2), in contrast with results from Japan of increased survivorship with increasing seed size up to about 70 mm (Inoue 1976). Our one year mortality estimates based on the collection of shells suggest that more of the larger CMA seed died than the smaller MCL abalones (test of equality of percentages, $P = .035$). We are reluctant to accept this result because of the significantly greater movement, which could lead to both increased dispersal and greater exposure to predation, exhibited by the MCL seed at the beginning of the experiment. Furthermore, shell collecting efficiencies declined with distance from the planting site and while we have little evidence that many shells were broken into unrecognizable fragments, the smaller MCL seed would be more susceptible to this fate. Lower mortality of the smaller seed is contrary to both the Japanese results and the general assumption that small animals have a higher mortality rate than larger, thicker shelled individuals.

The Japanese report higher survivorship in their seeding experiments. Recent results include those of Momma *et al.* (1980) who obtained 17% survival of 15 mm and 33% survival of 21 mm *Haliotis discus hannai* seed one year after planting in a concrete crib filled with 30–50 cm rocks partially covered by a protective lattice. Sakamoto, Tanaka and Kobayashi (1982) report 13% recovery of *H. discus discus* seed ranging from 15 to 50 mm over several years on concrete artificial reefs. Miyamoto *et al.* (1982) obtained less than 10% survival for *H. discus hannai* less than 10 mm and 23 to 31% survival for seed greater than 22 mm after 491 days in natural habitat. Saito (1984) reported 5 to 10% recapture rates for hatchery-reared *H. discus hannai* two to three years after planting. Inoue (1976), who reported one year survival rates greater than 60% for *H. gigantea*, *H. sieboldi* and *H. discus* 40 mm and above, stressed that recapture rates vary with species, size at planting, and depth and habitat of the plant site. For comparison with seeding experiments in California, it should be noted that the Japanese have intensive fisheries for octopuses, crustaceans and gastropods, and it seems certain that predator fisheries reduce the impact of the predators on small abalones.

The high observed mortality of both seed and native red abalones raises questions about the intensity of predation pressure, especially by octopuses, at Palos Verdes. Most of the octopuses collected at this site were either *O. bimaculoides* or *O. bimaculatus*, sibling species which are nearly indistinguishable

morphologically but are separated by egg size, juvenile life style, and kidney parasites (Ambrose 1982b). Their geographic and depth distributions overlap and both are known from kelp forests (Hochberg and Field 1980). *Octopus rubescens* was also taken. As all three species are known to prey on molluscs (Hochberg and Field 1980), they were lumped for the purposes of this study. Ambrose (1982a, b) reports densities of *O. bimaculatus* at Santa Catalina Island ranging from 0 to 3 per 100 m²; we found 3 octopuses in 70 one m² samples. Forty octopuses were collected from the 625 m² seeding site over the course of the year and more were observed. Schmitt and coworkers recovered 529 shells from a red abalone seeding experiment near Santa Barbara; only 1% of these shells were drilled by an octopus (Tegner *et al.* 1981) versus 32% for seed and 38% for natives in the present experiment. It is not known why octopus populations at Palos Verdes are so large but considerable experience here suggests that this was not an anomalous year. Octopus predators include the California moray, *Gymnothorax mordax*; California scorpionfish, *Scorpaena guttata*; basses, *Paralabrax* spp.; rockfishes, *Sebastes* spp.; and cabezon (Quast 1968, Hochberg and Fields 1980). Morays and rockfishes are rare at Palos Verdes while cabezon are commonly observed in very low numbers (pers. observation).

The densities of the other predators and carnivorous scavengers at Palos Verdes do not seem unusual. The Palos Verdes densities of *Astrometis* and *Panulirus* are less than the maximum values observed at nearby Santa Catalina Island (Schmitt 1982). The density of *Kelletia* at Palos Verdes is five times the maximum value reported for Santa Catalina Island but less than the value reported for Del Mar, a site north of San Diego (Rosenthal 1971). The density of *Pisaster giganteus* at Palos Verdes (1.9/10m²) is marginally higher than the maximum (1.7/10m²) value observed at Santa Catalina Island (Schmitt 1982).

Data from a different series of experiments at Palos Verdes provide evidence that collections of scavengers and predators improve the survival of transplanted abalones, in this case reproductively-mature (156 mm average size) native green abalones, *H. fulgens* (Tegner and Butler, unpublished data). No predators or scavengers were removed on a small preliminary transplant and the mortality, based on the collection of individually tagged shells, was 42% of the total planted. During the subsequent transplant, we collected predators and scavengers in the immediate vicinity of the transplants; mortality was 21%. Far-ranging collections on the third transplant to the same site reduced mortality to 12%. By the final transplant, our catch of predators and scavengers per-unit-effort decreased substantially suggesting that we were impacting these populations; transplanted abalone mortality was 7%. Thus we believe that the initial collections of predators and scavengers substantially reduced transplant mortality of the red abalone seed at Palos Verdes Point. The effectiveness of subsequent collections is less obvious. Presumably many more seed would have been eaten if the predators had not been removed; nevertheless the data do suggest that nearly continuous predator control would be required to substantially improve survivorship.

The high observed mortality of native red abalones in this experiment and the results of Hines and Pearse's (1982) study of abalone populations in Monterey Bay suggest that abalone populations are very dynamic. Since we have no evidence that native red abalone density changed, the high mortality must have been balanced by a high recruitment (including both settlement and immigra-

tion) rate. The calculated native red abalone mortality rate was much higher than the observed seeded abalone mortality rate (Table 3). While the large confidence intervals around the original population estimate make it difficult to quantify the difference, the result is expected if we assume that small abalones have a much higher mortality rate than larger ones (Hines and Pearse, 1982). Hines and Pearse (1982) used three different methods, including the production rate of empty shells, to calculate the turnover of native red abalones in the Hopkins Marine Life Refuge. They obtained values ranging from 92% to 231% per year for a population which had had a stable density for at least eight years. Thus there is precedent for red abalone populations persisting under intense predation pressure.

In 1977, the California Legislature closed the coastline between Palos Verdes Point and Dana Point to all abalone fishing to allow recovery of depleted stocks. The results of this experiment, conducted about 0.5 km inside the northern boundary of the closure, have implications for the recovery of abalone populations at Palos Verdes. First, an average growth rate of about 30 mm/year (Table 2) compared favorably with published data (Leighton 1968); there is no reason to assume that food supply or other environmental parameters are not suitable. Second, while there is evidence that the recovery of green and probably pink abalone, *H. corrugata*, populations at Palos Verdes are limited by larval dispersal (Tegner and Butler in press), the data from Palos Verdes Point and several nearby locations (D. Parker, Calif. Dept. Fish and Game, pers. commun.; Tegner and Butler, unpublished data) indicate that red abalones are recruiting in good numbers to the Palos Verdes Peninsula. The high turnover rates suggest that predation pressure on juveniles is the primary limitation to the growth of red abalone populations in this area. Future management efforts to enhance abalone populations at Palos Verdes must somehow take this into account.

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INTERMARSH MOVEMENTS BY LIGHT-FOOTED CLAPPER RAILS INDICATED IN PART THROUGH REGULAR CENSUSING¹

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The light-footed clapper rail, *Rallus longirostris levipes*, a state and federally listed endangered species, was monitored at five coastal marshes on or in the vicinity of Camp Pendleton, U.S. Marine Corps Base, San Diego County, California. Monitoring was accomplished mostly through censusing for vocal responses to systematic playing of recorded calls during both morning and evening hours on 13 dates spanning the period 10 May–22 November 1983. The results of monitoring the relatively larger breeding population at Agua Hedionda Lagoon, the single study site located off the base, aided in the interpretation of results at the other four marshes. A small breeding population was verified at the mouth of the Santa Margarita River and dispersing transients were detected at Las Flores Marsh. The evidence for movements by light-footed clapper rails away from home marshes is presented and discussed.

INTRODUCTION

The light-footed clapper rail was listed as endangered, pursuant to both State and Federal endangered species laws, because of loss and degradation of habitat and resulting population declines. The number in California is relatively small, varying from 173 to 249 pairs distributed in 11 to 18 marshes, as determined in 1980 through 1983 with censusing by vocalizations (Zembal and Massey 1981, Massey and Zembal 1983).

Prior to a spring survey conducted in 1982, clapper rails had not been recently reported from marshes on Camp Pendleton in northern San Diego County (Wilbur 1974, Wilbur *et al.* 1979, Zembal and Massey 1981, Massey and Zembal 1983). A small population of one or two pairs was detected in the marsh at the mouth of the Santa Margarita River during the springs of 1982 and 1983. The light-footed clapper rail is generally thought to be quite sedentary and these birds might represent the remnant of a once larger population from a time when the Santa Margarita marsh was much more expansive and pristine. The lack of earlier records probably reflects less rigorous early censusing techniques (Zembal and Massey 1981), a relative lack of vigilance or failure of field workers to report their observations, and the great difficulty involved in detecting a small population.

Clapper rails were also discovered at the mouth of Cockleburrr Canyon in the spring of 1982. Responses to playbacks of taped vocalizations indicated the presence of at least four individuals on 12 March 1982 (Harold A. Wier, environmental consultant to U.S. Navy, pers. commun.), but by 24 March 1982 only a single individual was detectable. This raised questions concerning the residency of these rails versus the repeatability of clapper rail responses to taped vocalizations over time. In light of these observations on Camp Pendleton and the endangered status of this subspecies, the light-footed clapper rail became a

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species of concern with regard to the U.S. Navy's proposed Landing Craft Air Cushion Operational Base Project (LCAC), and a monitoring study of the adjacent marshes was funded.

The purpose of this investigation was to gather information on use by clapper rails of the marshes nearest the proposed project site, (i) the mouth of the Santa Margarita River, (ii) Cocklebur Canyon, (iii) French Canyon, and (iv) Las Flores Marsh; and to investigate the evidence for long-range movements by light-footed clapper rails. In so doing, it was necessary to establish the rail's responsiveness to taped calls over a seven-month period.

STUDY SITES AND METHODS

Clapper rails were monitored on a regular basis at the above mentioned four marshes and the marsh on the inland fringe of upper Agua Hedionda Lagoon southeast of Carlsbad, California (Figure 1). These marshes were censused for rails on 13 dates, 10 May–22 November 1983. Two observers participated on each census date; at the same time one person censused Agua Hedionda and the river mouth, the other censused Cocklebur and Las Flores. On each census date, each of the four marshes was censused in the early morning (starting near dawn) and again in the late evening (finishing near sunset), resulting in 26 censuses at each marsh. French Canyon was added to the study later and was visited on only three occasions, 6 July–18 October 1983. Monitoring the small but better known populations at Agua Hedionda and the river mouth served as a comparison to aid in the interpretation of the results at the three smaller marshes. The vocal responsiveness of the rails at the two established sites gave an indication of what temporal variability to expect from a small (about 7 pairs) and very small (1 or 2 pairs) population.

Audio tape recordings of the clapping call were played at each of about ten stations at a marsh during each visit (the calls were recorded at Upper Newport Bay, Orange County, California). The call was played a maximum of three times at a station, with roughly one-minute delays between playings. Stations were spaced at nearly equal intervals along each marsh. Every time a response was obtained, the observer quickly turned off the tape recorder and abandoned further playing at that station, noted the compass direction and approximate distance of the responding rail(s), identified whether each response was from a single or a pair of birds, recorded the time and type of response, placed a numbered flag at the station, and noted general vegetational characteristics in the vicinity of the calling bird.

The same census routes were followed each time, but the locations of stations for tape playing varied, to avoid over-stimulation of responding rails, and the routes were periodically reversed. The stations were spaced closely enough that a bird anywhere in a marsh was likely to hear the tape playing from several different stations. This overlap was necessary because the rails usually responded much more readily to a nearby call. Censusing took an average of about one hour per marsh.

Between morning and evening censuses, direct observations of rails were attempted at the marshes on Camp Pendleton on 6 of the 13 dates of visitation. Searches for nests were conducted in the late summer, thrice at Las Flores and once at the river mouth. All suitable habitat was covered.

Marsh habitats at each study site were characterized by a mixture of cattails,

Typha spp., bulrush, *Scirpus* spp., intermixed willows, *Salix* spp., and fringing stands of salt marsh species, particularly pickleweed, *Salicornia virginica*. Of the study sites, the largest expanse of marsh is present at the river mouth. The marsh environs there total about 127 ha and are comprised approximately of 51 ha of open flats, 50 ha of salt marsh, 24 ha of mudflat/open water, and 2.4 ha of brackish marsh. Only the approximately 16 ha of northernmost marsh were covered routinely. Roughly 20 ha of marsh comprised the study area at Agua Hedionda, and Las Flores Marsh totalled about 14 ha along the creek and north marsh, combined. The canyon bottoms at Cockleburrr and French Canyons comprised about 8 ha and 5 ha, respectively.

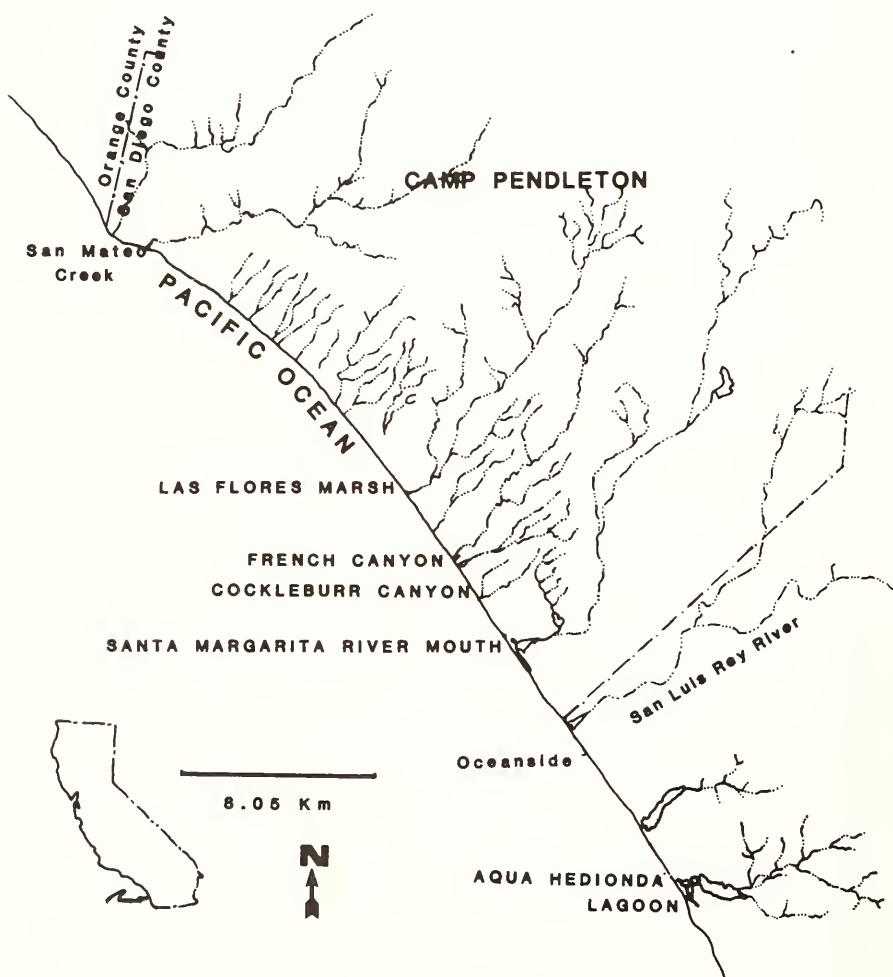


FIGURE 1. Locations of clapper rail study sites, San Diego County, California.

More complete descriptions of the habitats of the study sites on Camp Pendleton are available in the final EIS for the LCAC project (Nav Fac 1982). A more detailed description of the river mouth environs was prepared by Salata (1981). The habitats of Agua Hedionda Lagoon are discussed by Bradshaw *et al.* (1976) (see also Zembal and Massey 1981).

RESULTS

During the study, 106 vocalizations were recorded (Table 1). Most of these calls were given in apparent response to the playing of taped clapping calls. Of the total, 72.6% was clapping, 23.6% was kecking, and 2.8% was agitated kecking. Also, there was one chase squeal (0.9%).

We obtained no responses from clapper rails at Cockleburrr or French Canyons. In contrast, the response to recorded clapping calls was relatively high at both marshes where resident populations are suspected and was sporadic at Las Flores (Table 1). The response rate from the smaller population at the river mouth was lower than that obtained from the larger population at Agua Hedionda, but was still relatively consistent. This is in keeping with observations throughout the range of *R. l. levipes*—vocalizations are less frequent from smaller populations and detection of a small population is not guaranteed on any single visit, even with the use of taped calls (Zembal and Massey 1981).

Mid-day visual observations and searches for nests added only limited information to what had already been surmised through censusing by vocalizations at the marshes on Camp Pendleton. Observations and searches for nests on three dates at Las Flores revealed no additional activity by clapper rails. After a few minutes searching at the river mouth on 10 June 1983, however, the pair's nesting site was discovered. The site was located near the base of the north bluff in the Sweetwater Marsh area, where salt marsh and brackish marsh meet. The incubation nest was built in alkali bulrush, *Scirpus robustus*, on the edge of a small pond bordered by cattails, willows, and pickleweed. There were two brood nests found in cattails located about 2m apart and about 12m away from the incubation nest. Fragments of regurgitated pellets were observed in one of the brood nests and there were small egg shell fragments in the incubation nest. The presence of brood nests and shell fragments are both indicative of successful hatching of at least one chick (Massey, Zembal and Jorgensen 1984). The presence of food remains and pellet fragments in a brood nest, and the conditions of the brood nests indicated that one was still in use.

Exploration of the entire marshes at the four sites studied on Camp Pendleton revealed a low number of suitable nesting sites. The lack of adequate nesting habitat appears to be a major limiting factor for light-footed clapper rails throughout their range (Massey *et al.* 1984, Zembal and Massey 1983), including the marshes on Camp Pendleton. Suitable nesting sites must be high enough to be protected from high tides, and isolated enough in a marsh to be effectively protected from upland predators. The best site observed at the river mouth was in use, and one other marginal, less isolated site, was not. Predator access to the marshlands at Cockleburrr and French Canyons appeared to be unimpeded, whereas a few marginally isolated locations were found at Las Flores (one was used successfully by a pair of nesting American coots, *Fulica americana*).

TABLE 1. Responses by Light-footed Clapper Rails to Systematic Playing of Taped Clappering Calls at Three Marshes in San Diego County, California

Date	Time	Agua Hedionda Lagoon			Santa Margarita River Mouth			Las Flores Marsh		
		Points ¹	Calls ²	Ind ³	Points	Calls	Ind	Points	Calls	Ind
	AM	5	6	5	2	2	2	1	1	1
10 May	PM	5	5	5	2	2	2	0	0	0
	AM	2	2	2	1	2	2	0	0	0
23 May	PM	3	4	4	1	1	1	0	0	0
	AM	4	5	5	1	1	1	0	0	0
10 June	PM	3	3	3	0 ^a	0	0	0	0	0
	AM	4	4	4	1	1	1	0	0	0
22 June	PM	4	4	4	1	1	1	0	0	0
	AM	1	1	1	0	0	0	0	0	0
6 July	PM	1	2	2	0	0	0	0	0	0
	AM	2	2	2	0	0	0	0	0	0
19 July	PM	2	2	2	0	0	0	0	0	0
	AM	2	2	2	1	2	2	0	0	0
11 Aug.....	PM	1	1	1	1	1	1	0	0	0
	AM	1	1	1	1	1	1	1	1	1
26 Aug.....	PM	2	2	2	0	0	0	0	0	0
	AM	1	1	1	1	1	1	0	0	0
13 Sept	PM	0	0	0	1	2	2	0	0	0
	AM	4	4	4	- ^b	-	-	0	0	0
6 Oct.....	PM	3	4	4	1	1	1	1	2	2
	AM	5	7	7	1	1	1	0	0	0
18 Oct.....	PM	3	5	5	0	0	0	0	0	0
	AM	4	5	5	1	1	1	0	0	0
31 Oct.....	PM	2	3	3	1	1	1	0	0	0
	AM	4	4	4	0	0	0	0	0	0
22 Nov	PM	2	2	2	0	0	0	0	0	0
% of all dates responses obtained:		100			76.9			23.1		
% of all censuses responses obtained:		96.2			64			11.5		

¹ Points from which responses were obtained by one or more rails, but usually a single or pair.² Where the total number of calls is greater than the number of points, one or more duet clapperings were heard.³ Total number of individuals documented.^a Birds were disturbed by nest-searching, just prior to this census.^b Aerial spraying and pesticide fog precluded censusing.

DISCUSSION

Evidence for clapper rail use of Las Flores Marsh was unmistakable, but of less intensity than expected for a resident population, as indicated by comparisons with our results at Agua Hedionda Lagoon and the river mouth. Detectability of clapper rails was mostly negative at Las Flores Marsh and entirely so at Cocklebur Canyon. This indicates that clapper rails detected at Las Flores Marsh in 1983 and those at Cocklebur Canyon in 1982 were most probably transients.

There are numerous small pockets of marsh and a few more extensive marshes in the approximately 28 km stretch of coast, mostly along Camp Pendleton from the mouth of the San Luis Rey River to the mouth of San Mateo Creek. The young produced at the mouth of the Santa Margarita River, and/or some other unknown locality(ies), presumably dispersed in search of more suitable territories that included better nesting habitat, and were detected enroute, subsisting for a time at Cocklebur Canyon or Las Flores Marsh. Such movements would

be facilitated by the relatively short distances between the many pockets of marsh in this area. We have found clapper rails in southern California nesting in marshes that vary from nearly monotypic stands of pickleweed to entirely freshwater systems (Zembal and Massey 1981, Massey and Zembal 1983). Although much more work is needed, our present knowledge indicates that food is not a major limiting factor to clapper rails in these various habitats, whereas the availability of suitable nesting locations is (Zembal and Massey 1983).

Although movements from home marshes by another, usually sedentary race, the California clapper rail, *Rallus longirostris obsoletus*, have been well documented (as summarized in part by Orr 1939), past accounts of wanderings by *R. l. levipes* have been somewhat sketchy (see Brooks 1940) and largely discounted (Wilbur and Tomlinson 1976). Indirect evidence of movements by light-footed clapper rails now exists in the form of acceptable sightings in small, disjunct inland patches of marsh. The following three examples are particularly well documented.

A solitary clapper rail was watched for 30–45 minutes along the shoreline at Walnut Canyon Reservoir (Nohl Ranch Lake), Orange County, on 19 October 1979 (Isabel Ludlum and Candice Dean, avid birders, pers. commun.). The lake is nestled in the Anaheim Hills about 22.2 km from the coast and 23.5 km from Upper Newport Bay (the nearest known population center for rails). The site is located about 3.2 km from the Santa Ana River (which is channelized), the nearest large, potential corridor of dispersal.

The vocalization of two birds were heard (including duet clapping) and one of them was observed on the fringe of a pond at the Whittier Narrows Recreation Area, Los Angeles County, on 6 January 1983 (David R. Bontrager, wildlife biologist, U.S. Fish and Wildlife Service, pers. commun.). Clapper rails were heard there again in late August (Baxter and Garrett 1983). Whittier Narrows is located about 30.6 km from the ocean and about 32.2 km from the Seal Beach National Wildlife Refuge (the nearest known population center). The Rio Hondo and San Gabriel River beds (channelized) are adjacent to the site and empty in the ocean near the Refuge.

Two birds were heard at Guajome Lake, San Diego County, on both 1 and 6 April 1983 (Larry R. Salata, wildlife biologist, U.S. Fish and Wildlife Service, pers. commun.). The lake is located about 11.7 km from the coast, 0.8 km from the San Luis Rey River, and 12.9 km from the mouth of the Santa Margarita River.

The most definitive evidence for long-range movements by light-footed clapper rails has come as a result of banding (since March 1981) and telemetry (since August 1981) studies conducted at Upper Newport Bay. Established birds appear to be extremely site tenacious. Others, particularly first-year birds, have been sighted well away from their original capture sites, apparently in search of unoccupied territories within the bay. To date, 54 clapper rails have been individually color banded and only one has been observed away from Upper Newport Bay. This individual, a large male, was banded (band #825-39432) on 9 September 1982 at the south end of Shellmaker Island in Upper Newport Bay. He was seen four times through 5 October within 90m of the trap site. On 29 December 1982 he was sighted again, but this time within the Seal Beach National Wildlife Refuge during a high tide count, (Dr. C. T. Collins, Cal. S. Univ., Long Beach, pers. commun.), 21.7 km from the original capture site. This is the farthest movement documented for an individual light-footed clapper rail.

We do not know how often or how far light-footed clapper rails move but the advantage of some, at least local, movement seems clear. If nesting sites remain limiting at the mouth of the Santa Margarita River, for example, rails must move in and out or the young produced there would be doomed to inbreeding and then only after a probable lengthy wait for one of very few unoccupied adequate sites. Additionally, during certain years a marsh's vegetation could be devastated by storm tides and flood flows, ruining much of the nesting habitat for rails in the lower marsh and greatly reducing the available food supply for a time (by massive freshwater intrusion and scour from high flows—see Massey *et al.* 1984). The ability to move, subsist for a time, and possibly nest in marginal habitat could save a portion of a population when conditions are poor in the home marsh, resulting in some recruitment through breeding that otherwise might not have occurred.

Movements between parcels of marsh may be uniquely common along the coast of Camp Pendleton, where many small pockets of marsh occur close together, but good nesting sites are extremely scarce. Apparent transients have been detected there during both of two consecutive years that at least limited monitoring of rails has been accomplished. The lack of concurrent detections at Cocklebur Canyon and Los Flores marsh during either year could be due to a variety of factors including conditions for clapper rails that vary from year to year and marsh to marsh, the frequency of our sampling, variability in the responsiveness of the rails, or merely the small number of birds present.

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BIRD DIETS AND PREY AVAILABILITY IN THE WESTERN SIERRA NEVADA, CALIFORNIA¹

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We analyzed the stomach contents of 199 birds of 27 species collected in the western Sierra Nevada during 1980. The availability of certain prey was also assessed. Only nine of the bird species showed over 10% vegetable matter in their stomachs. Sparrows and a finch showed the highest content of vegetable matter. Birds usually considered insect eaters had a high content of animal matter. Most items were insects except for spiders and snails. Data indicated the wide variety of food items taken by birds in the western Sierra Nevada.

INTRODUCTION

The role of birds in forest ecosystems has long intrigued biologists. Of special interest both ecologically and economically is the effect of bird predation on insects. Although some attention has been given this topic, results are equivocal, with some authors concluding that birds prevent or control insect outbreaks, while others ascribe birds a reduced role (Bruns 1960; Tinbergen 1960; Otvos 1965; McCambridge and Knight 1972; Holmes, Schultz, and Nothnagle 1979; Torgersen and Campbell 1982).

Before the effect of birds on their prey base can be determined one must first assess the prey available and taken by the birds. It was thus the objective of this paper to present data on prey availability and prey taken by birds in a mixed-conifer forest of the western Sierra Nevada. Further, we hope that these baseline data will generate further research into the role of birds in California forests.

STUDY AREA AND METHODS

We analyzed stomachs from birds collected at the Blodgett Forest Research Station of the University of California-Berkeley, El Dorado County, California. The 1500 ha study area is a mixed-conifer forest on the west slope of the Sierra Nevada at about 1400 m elevation. The forest is characterized by mature Douglas fir, *Pseudotsuga menziesii*; white fir, *Abies concolor*; ponderosa pine, *Pinus*

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ponderosa; sugar pine, *P. lambertina*; incense cedar, *Calocedrus decurrens*; and black oak, *Quercus kelloggii*. A complete description of this area was given by Airola (1979) and Cohen (1982).

During June and July 1980, 199 birds were collected using mist nets. These dates correspond to the nesting period of most birds at Blodgett. Stomachs were taken from the birds and stored in vials of 70% ethanol. Twenty-seven species were collected; sample sizes ranged from 1 to 25. Stomach contents were analyzed in March 1983.

Stomach volumes were measured by displacement, i.e., 2 to 3 ml of 70% ethanol were poured into a 5 ml volumetric flask and measured to the nearest 0.1 ml. Stomach contents were scraped into the flask and the difference between the new and original volume recorded. Flask contents were emptied into glass petri dishes and placed over one-tenth inch grid paper. The proportions of each of mineral (grit), vegetable, and animal matter were measured. This was done by counting the number of $\frac{1}{10}$ inch squares covered by each type of material.

Contents in the petri dishes were sorted for identifiable items and/or parts. We attempted to estimate numbers of individuals within a given taxonomic group. Many stomach contents were too ground up to identify beyond "insect". Due to these problems, we chose to record only the presence or absence of the various animal forms. The items were recorded by life stage (egg, larva, pupa, and adult) and classified to the lowest taxon possible.

One sticky trap was placed on the bole at three heights (5, 10 and 15 metres on each of eight randomly selected trees for a 2 wk period in June and July 1980 (notes recording tree species used were lost). The traps were 15 x 30 cm, 6 mm mesh hardware cloth screens and were coated with Stick-em Special[®] (Michel and Polton, Emeryville, California.). The purpose was to trap prey items in areas where the birds were foraging, and to obtain information on abundance (qualitative measure primarily and a general quantitative measure).

The traps were cleaned in hot kerosene in the laboratory and the items were placed in kerosene-filled screw cap vials. The vials were stored until early 1983 when the vials were drained and replaced with 70% ethanol.

RESULTS AND DISCUSSION

Only nine of the 27 bird species showed over 10% vegetable matter in their stomachs (Table 1). Of these nine species, only the purple finch (scientific names in Table 1), fox sparrow, and chipping sparrow showed over one-third vegetable matter; the chipping sparrow (at 79.1% vegetable matter) was represented by only one individual.

These results are mostly consistent with the feeding habits of the species. That is, high animal percent for "insect" eaters (e.g., vireos, warblers, flycatchers) and high vegetable percent for "seed" eaters (e.g., sparrows). Several exceptions are noteworthy, however. The dark-eyed junco, usually classified as a "ground-seed forager" (Martin, Zim and Nelson 1951), showed 74.6% animal matter. This is in contrast to other "seed-eaters", such as the fox sparrow. Likewise, the black-headed grosbeak, another species seemingly adapted to seed eating, showed only 1.4% vegetable matter in its stomach. It is not unusual, however, for species adapted to seed-eating (i.e., heavy bill) to take large quantities of animal matter during the nesting period (e.g., see Martin *et al.* 1951). Of course, this does not explain why other seed-eaters did not show

higher percentages of animal matter in their stomach. In contrast, the yellow-rumped warbler, a bird usually associated with insect-gleaning in forest canopies, showed 18.9% vegetable matter. It is possible, of course, that much of the vegetable matter in the stomach of this warbler was accumulated incidentally while foliage-gleaning for insects.

Further identification of animal content in the stomachs revealed about 40 groupings of animals at various taxonomic levels; some of these groups were divided by life stage (Table 2). Most items in the stomachs were insects except for some spiders and snails. Of these groups, ten or more appeared in the stomachs of seven bird species. Adult coleopterans (especially weevils), homopterans (especially cicadellids), hymenopterans (especially formicids), and spiders (araneida); larval lepidopterans, and dipterans of various life stages were the most frequently observed items. Because of wide variations in sample size among bird species, a rigorous analysis of the frequency of occurrence of stomach items is inappropriate. Thus the rare occurrence of an item in the stomach of a particular species, while possibly significant after accumulation of a larger sample, should only be listed without undue speculation at this time.

It is interesting, however, that several species with good sample sizes varied widely in the frequency of occurrence of certain stomach items. For example, the golden-crowned kinglet ($n = 9$) showed only five identifiable items. In contrast, the black-headed grosbeak ($n = 7$) showed 14 identifiable items. Further, the dark-eyed junco ($n = 22$) and *Empidonax* flycatchers ($n = 25$) showed only 12 and 14 items each, respectively. These results could be an indication of specialization or generalization in food habits by certain species.

About three-quarters of the items obtained from the sticky traps were dipterans (Table 3). Hymenopterans and homopterans were the only other groups with over 7% occurrence. Most items were identified to at least the familial level and are available from the authors (but are too numerous to present here).

TABLE 1. Analysis of Stomach Contents of 27 Species of Birds by Percent Animal, Vegetable and Mineral Material, sampled at Blodgett Forest, El Dorado County, California, June-July 1980.

Species ^a	No. of stomachs	Volume (ml)		Stomach contents (%)		
		$\bar{x}$	SE	Mineral	Vegetable	Animal
Red-breasted sapsucker	8	0.49	0.12	0.0	11.7	88.3
<i>Sphyrapicus ruber</i> (RBSA)						
Olive-sided flycatcher	1	0.25	0.00	0.0	0.0	100.0
<i>Contopus borealis</i> (OSFL)						
<i>Empidonax</i> flycatcher ^b (EMFL)	25	0.22	0.03	0.0	1.0	99.0
Steller's Jay	1	1.40	0.00	0.0	0.0	100.0
<i>Cyanocitta stelleri</i> (STJA)						
Chestnut-backed chickadee	2	0.10	0.00	0.0	18.2	81.8
<i>Parus rufescens</i> (CBCH)						
Brown creeper	5	0.06	0.02	0.0	0.0	100.0
<i>Certhia americana</i> (BRCR)						
Golden-crowned kinglet	9	0.10	0.02	0.0	27.5	72.5
<i>Regulus satrapa</i> (GCKI)						
Townsend's solitaire	2	0.35	0.12	0.6	1.0	98.4
<i>Myadestes townsendi</i> (TOSO)						

TABLE 1. Analysis of Stomach Contents of 27 Species of Birds by Percent Animal, Vegetable and Mineral Material, sampled at Blodgett Forest, El Dorado County, California, June–July 1980.—Continued

Species ^a	No. of stomachs	Volume (ml)		Stomach contents (%)		
		$\bar{x}$	SE	Mineral	Vegetable	Animal
Hermit thrush	12	0.24	0.07	0.0	1.3	98.7
<i>Catharus guttatus</i> (HETH)						
American robin	14	0.73	0.12	0.2	0.3	99.5
<i>Turdus migratorius</i> (AMRO)						
Solitary vireo	6	0.13	0.04	0.6	0.0	99.4
<i>Vireo solitarius</i> (SOVI)						
Warbling vireo	6	0.16	0.05	0.0	1.3	98.7
<i>V. gilvus</i> (WAVI)						
Nashville warbler	12	0.07	0.01	1.0	0.9	98.1
<i>Vermivora ruficapilla</i> (NAWA)						
Yellow warbler	4	0.09	0.03	20.0	0.0	80.0
<i>Dendroica petechia</i> (YEWA)						
Yellow-rumped warbler	3	0.17	0.03	0.0	18.9	81.1
<i>D. coronata</i> (YRWA)						
Black-throated gray	1	^c	0.00	0.0	0.0	100.0
warbler— <i>D. nigrescens</i> (BTGW)						
Hermit warbler	6	0.10	0.02	1.5	7.9	90.6
<i>D. occidentalis</i> (HEWA)						
MacGillivray's warbler	15	0.10	0.02	0.0	0.0	100.0
<i>Oporornis tolmiei</i> (MAWA)						
Wilson's warbler	8	0.07	0.02	1.0	3.3	95.7
<i>Wilsonia pusilla</i> (WIWA)						
Western tanager	2	0.90	0.00	2.5	2.5	95.0
<i>Piranga ludoviciana</i> (WETA)						
Black-headed grosbeak	7	0.67	0.09	0.2	1.4	98.4
<i>Pheucticus melanocephalus</i> (BHGR)						
Rufous-sided towhee	6	0.68	0.24	2.7	13.2	84.1
<i>Pipilo erythrophthalmus</i> (RSTO)						
Chipping sparrow	1	0.20	0.00	2.9	79.1	18.0
<i>Spizella passerina</i> (CHSP)						
Fox sparrow	13	0.23	0.05	5.6	47.4	47.0
<i>Passerella iliaca</i> (FOSP)						
Dark-eyed junco	22	0.15	0.02	17.9	7.5	74.6
<i>Junco hyemalis</i> (DEJW)						
Purple finch	7	0.18	0.03	17.7	34.6	47.8
<i>Carpodacus purpureus</i> (PUFI)						
Evening grosbeak	1	0.40	0.00	2.7	24.0	73.3
<i>Coccothraustes vespertinus</i> (EVGR)						

^a Common and scientific names follow AOU (1983).^b *E. hammondi* and *E. oberholseri*; specimens not retained so positive identification not possible.^c Not available.

The sticky trap data gave only a cursory indication of prey available to the birds. At best, these traps sample insects found at least occasionally on tree boles; they did not sample foliage dwelling insects. This may in part account for the low frequency of dipterans in stomach samples (8 of 27 bird species) relative to trap samples. The four remaining items with the highest trap frequency were: hymenopterans, homopterans, spiders, and coleopterans. These were also some of the most frequently observed stomach items.

CONCLUSIONS

This paper provides identification of the stomach contents of birds occurring in a coniferous forest of the western Sierra Nevada, as well as a crude estimate of available prey. It is hoped that these data will serve as useful baseline material for future studies.

TABLE 2. Presence of Animals in Stomachs (n = 199) of 27 Species of Birds by General Taxon. Birds Collected at Blodgett Forest, El Dorado County, California, in June-July 1980.^a—Continued

Taxon ^b	RBSA	OSFL	EMFL	STJA	BRCR	CBCH	CCKI	TOSO	HETH	AMRO	SOVI	WAVI	NAWA	YEWA	YRWA	BTGW	HEWA	MAWA	WIWA	WETA	BHGR	RSTO	CHSP	FOSP	DEJU	PUEI	EVGR	Total
Mecoptera—A.									x																		1	
Lepidoptera—A.		x																									1	
—L.				x																							9	
Diptera—E.			x																								2	
—L.																											2	
—P.					x																						4	
Hippoboscidae—A.			x																								1	
Mycetophilidae—A.																											3	
Tipulidae—A.																											3	
—L.																											3	
Hymenoptera—A.			x																								1	
—P.																											8	
Formicidae—A.			x																								1	
Ichneumonidae—A.	x																										13	
Vespidae—A.		x																									1	
Symphyla—A.	x																										1	
—L.																											2	
Larva—unk.																											1	
Pupa—unk.																											6	
Other taxa																											1	
Gastropoda (snail spp.)—A...	x																										5	
Chilopoda—A.																											1	
Arachnida																											1	
Phalangida—A.																											1	
Araneida (spider spp.)—A.		x																									10	
Total	3	2	14	2	5	2	5	3	10	14	6	11	8	10	3	1	8	8	4	5	14	7	2	6	12	7	3	175

^a See Table 1 for reference to bird species.^b Unk. = unknown; A = adult; E = egg; L = larva; P = pupa.

TABLE 3. Occurrence of Items on Sticky Traps on Trees at Blodgett Forest, El Dorado County, California, June-July 1980.

Order	Number items	Percent	Cumulative percent
Diptera	7,263	76.8	76.8
Hymenoptera	1,025	10.8	87.6
Homoptera	709	7.5	95.1
Arachnida (spiders)	158	1.7	96.8
Coleoptera	120	1.3	98.1
Thysanoptera	61	0.7	98.8
Hemiptera	52	0.6	99.4
Neuroptera	25	0.3	99.7
Lepidoptera	16	0.2	99.9
Psocoptera	15	0.2	100.1
Others	9	0.1	100.2
Total °	9,453	—	—

° Other unidentified specimens (and parts of specimens) are not included in this table.

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DETERMINING THE SEX OF SEA OTTERS FROM SKULLS¹

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The sex of sea otter, *Enhydra lutris*, skulls can be determined from five measurements (total skull length, condylobasal length, zygomatic width, mastoid width, and diameter of upper canine). Key Values, which separate male and female measurements, were determined from bar graphs representing data from 326 known-sex, adult skulls from six regions along the North American Pacific coast. If all five measurements are available for a particular skull, a Sum Index can be developed which allows sex determination with even greater accuracy.

INTRODUCTION

Mammal skulls have considerable value for many types of studies, including population age distributions, sex ratios, mortality rates, and for taxonomic research. The remains of marine mammals are regularly washed up on our beaches, and the skulls of some of these animals are preserved to add to our knowledge of the less well known species. Besides the skull itself, as much additional information as possible should be recorded, including the sex of the animal. On occasion, the remains are so deteriorated that sex cannot be determined from the carcass, which makes the skull data less useful. This report presents a method for determining the sex of sea otter, *Enhydra lutris*, remains with reasonable accuracy from the skull alone.

Among many published reports on sea otters, few address the problem of sexing skulls. Scheffer and Wilke (1950) indicate some sexual differences in skulls, and these are further clarified in Scheffer (1951). Differences are also indicated by Roest (1973, 1979), but none of these papers present sufficient detail to be of help in determining the sex of a skull. Morejohn, Ames, and Lewis (1975) provided a means of sexing sea otters by examining the pelvic structure, but this bone is rarely preserved in museum collections.

The most obvious sexual difference in sea otters is that males are distinctly larger than females (as is true for most mustelids). Since males are larger, so too are male skulls, and it should be possible to determine the sex of a skull by making size comparisons. In general, large skulls are those of males, while small ones are female, but many medium-sized skulls could be from either large females or small males. Although the sagittal and occipital crests of males tend to be larger than those of females, these features are difficult to measure and also vary with the age of the individual. There are no other skull features which distinguish the sexes.

MATERIALS AND METHODS

Sets of measurements from 326 known-sex, adult sea otters were available. Some were from skulls previously studied (Roest 1973, 1979), but others were from skulls measured since that time. The skulls used in this study represent specimens from the following institutions: Alaska Department of Fish and Game,

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Anchorage, AK (81 skulls); American Museum of Natural History, New York, NY (1); California Academy of Sciences, San Francisco, CA (2); California Polytechnic State University, San Luis Obispo, CA (94); Humboldt State University, Arcata, CA (3); Loma Linda University, Loma Linda, CA (1); Moss Landing Marine Laboratories, Moss Landing, CA (4); Museum of Vertebrate Zoology, Berkeley, CA (11); National Museum of Natural History, Washington, D.C. (98); Pacific Grove Museum of Natural History, Pacific Grove, CA (2); Provincial Museum of British Columbia, Victoria, BC (5); Sacramento State University, Sacramento, CA (1); San Diego Museum of Natural History, San Diego, CA (2); Santa Barbara Museum of Natural History, Santa Barbara, CA (1); University of California, Santa Cruz, CA (20).

Only measurements from adult skulls were used, since juvenile animals are small and their small skulls would key out to being female on any distribution. Subadult skulls may be as large as those of adults, but often they are not. A skull was considered to be that of an adult if the basioccipital-basisphenoid suture on the lower surface of the braincase was closed. This suture remains open until the otter has reached adult size, at an age of about three years, although some growth may occur subsequently to produce exceptionally large individuals. It is a feature which has been taken to represent adults by several investigators (Lensink 1962, Roest 1973, 1979, Morejohn *et al.* 1975).

Four skull measurements were selected which indicate the overall size of the specimen: total skull length, condylobasal length, zygomatic width, and mastoid width. Since Scheffer (1951) indicated that the diameter of the upper canine tooth differed between the sexes, this was also included in the analyses. Each of these measurements was taken in millimetres with dial calipers, and is defined below and illustrated in Figure 1.

Total Skull Length (SkL): from the most anterior part of the premaxillae (bones supporting the incisor teeth) to the most posterior portion of the skull (usually some part of the occipital crest across the top, back part of the skull; measured to the nearest millimetre).

Condylobasal Length (CBL): from the most anterior part of the premaxillae to the posterior surface of the occipital condyles (swellings on either side of the foramen magnum, the large hole in the lower, back portion of the skull); measured to the nearest millimetre.

Zygomatic Width (ZW): greatest distance across the zygomatic arches, or cheek bones; measured to the nearest millimetre.

Mastoid Width (MW): greatest distance across the mastoid projections, the widest part of the skull behind the zygomatic arches; measured to the nearest millimetre.

Diameter of Upper Canine Tooth (Cd): greatest diameter of the upper canine tooth at the level where it emerges from its socket (alveolus); measured to the nearest one-tenth of a millimetre. This measurement may not be quite parallel to the main axis of the skull, as are SkL and CBL.

From the measurements, a series of bar graphs was developed, on which male and female measurements were plotted with different symbols. From the graphs, measurement characteristics of each sex could be determined, as well as measurements which represented overlapping values. A point (= measurement) was

selected on each graph such that most male measurements were plotted above it and most females below. The selected point, or "Key Value", was picked to produce the fewest incorrect or uncertain measurements.

Since sea otters in the northern parts of their range are larger than those from southern locations (Roest 1973, 1979), separate bar graphs were constructed for skulls from different parts of the range. These geographic groupings represented specimens from California (119), British Columbia-Washington-Oregon (9), Prince William Sound (22), the Alaska Peninsula (36), Adak Island (39), and Amchitka Island (101). Data are not available for sea otters from the Russian parts of the species' range.

A bar graph developed for condylobasal lengths for sea otters from California illustrates the method (Figure 2).

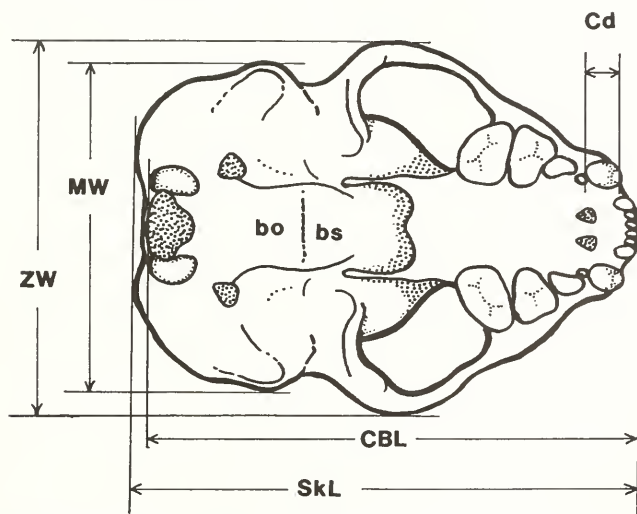


FIGURE 1. Skull measurements used to determine the sex of a sea otter skull. Cd = canine tooth diameter; CBL = condylobasal length; MW = mastoid width; SkL = total skull length; ZW = zygomatic width; bo and bs indicate the basioccipital and basisphenoid bones, between which lies the BO/BS suture. This suture is not visible in adult skulls.

In attempting to work out a relatively simple system for sexing otters, various combinations of these five measurements were tried, to see if a single value or formula could be developed. The most effective combination proved to be a simple summation of all the measurements, with one adjustment. Since the first four measurements all have values near 100 mm, while the canine tooth diameter is usually near 10 mm, the relative value of the canine in a summing combination is only one-tenth that of the others. To equalize the relative values of the measurements, the first four were converted to one-tenth their actual values. Thus a measurement of 104 mm was converted to 10.4 for summing. The resulting "Sum Index" of "one-tenth of each of the first four measurements, plus the full value of the canine tooth measurement" produced sums in the neighborhood of 50.

Measurement sets were not complete for every specimen, due to broken bones, missing teeth, or failure to take certain measurements at the time the skull was examined. As a result, the various bar graphs were not all constructed with

equal numbers of specimens. Calculation of the probable accuracy of a particular Key Value was determined separately for each graph, and indicates the percent of the actual number of specimen measurements graphed which were correctly sexed by the Key Value indicated.

Condyllobasal lengths: 62 males, 56 females (n = 118)

○ = females

● = males

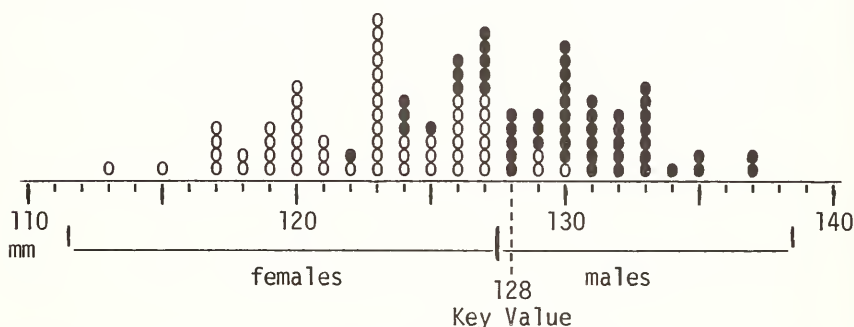


FIGURE 2. Plot of condyllobasal lengths for sea otters from California. The Key Value with the fewest incorrectly placed measurements is 128. A skull with a condyllobasal length of 128 mm or more is probably that of a male. Only 13 of 62 males had CBLs of *less* than 128, and only 3 females had a CBL *greater* than 128. The Key Value of 128 is correct for 102 of 118 sea otter skulls, or 86% correct. The smallest male has a CBL of 122 mm, the largest female has one of 130 mm.

RESULTS

Information to determine the sex of most sea otter skulls from North America was derived from the bar graphs developed from the skull measurements of known-sex, adult sea otter skulls (Table 1). In practice, the measurements of an unknown-sex skull should be compared to the Key Values in the table. If a particular measurement is as large as, or larger than, the corresponding Key Value, the skull is probably that of a male; if less than the Key Value, the skull is probably from a female.

The values for smallest male and largest female indicate the range within which size overlap occurs. Specimens with measurements which fall within this range may be incorrectly sexed with the Key Value indicated.

The accuracy (acc.), or % correct, provides an indication of the confidence the user can have in determining the sex of a skull which falls into the overlap range (SM-LF), and is based on the number of correctly assigned skulls among the total number of skulls graphed. Larger sample sizes provide better Key Values, but also show more overlap between males and females.

Several measurements which all have male values provide increasing confidence in correct sex determination. A skull with five "male" measurements is very likely that of a male. If only four measurements are male, and one falls into the female range, it is still probably a male. Problems in determination may develop when only two or three measurements indicate male (or female), the others falling into the female (or male) values. In these cases the Sum Index,

with its greater accuracy, can be helpful in correctly sexing the skull. Unfortunately, there are always a few skulls which cannot be correctly assigned to either sex.

TABLE 1. Key Values for Five Skull Measurements and their Sum Indices. These values can be used to determine the sex of adult sea otter skulls from various regions. Each entry includes the Key Value (KV), measurements of the smallest male and largest female (SM-LF), percent correctly sexed specimens (acc.), and the sample size on which the value are based (n, males/females). When using the table, be sure to use Key Values from the appropriate geographic region.

<i>Skull from:</i>	<i>SkL</i>	<i>CBL</i>	<i>ZW</i>	<i>MW</i>	<i>Cd</i>	<i>Sum Index</i>
California:						
KV	131	128	100	95	8.4	54
SM-LF	126-138	122-130	96-103	92-100	8.1-9.0	53-55
acc.	86%	86%	84%	79%	83%	92%
n	62/55	62/56	65/53	63/54	60/49	57/47
British Columbia-Washington-Oregon:						
KV	133	129	100	97	9.1	56
SM-LF	145-130	129-128	100-102	97/96	9.4-8.8	59.2-52.5
acc.	100%	100%	86%	100%	100%	100%
n	2/1	7/2	5/2	7/2	7/2	2/1
Prince William Sound:						
KV	133	131	103	100	9.1	56
SM-LF	134-128	131-131	94-104	101-98	10.0-9.0	57.9-53.1
acc.	100%	95%	90%	100%	100%	100%
n	5/1	13/9	12/9	9/9	5/4	3.1
Peninsular Alaska:						
KV	133	131	103	100	9.1	56
SM-LF	135-135	130-134	103-102	98-99	9.4-8.8	56.2-54.7
acc.	97%	94%	100%	96%	100%	100%
n	24/9	27/9	20/4	20/4	13/4	13/4
Adak Island:						
KV	141	133	103	98	9.1	56
SM-LF	141-140	129-136	103-103	96-98	9.1-9.6	57.1-56.0
acc.	100%	87%	97%	92%	92%	92%
n	11/28	11/28	11-22	10/27	11/27	10/21
Amchitka Island:						
KV	141	134	103	97	9.1	56
SM-KV	143-140	128-135	99-105	96-97	9.0-9.3	57.7-55.5
acc.	100%	90%	88%	94%	93%	100%
n	3/29	33/66	32/63	3/30	3/28	2/21

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NOTES

A TECHNIQUE TO SECURE SMALL MAMMAL LIVETRAPS AGAINST DISTURBANCE

The winds and livestock encountered while trapping small mammals with aluminum Sherman livetraps (8x9x22cm) in the Mojave Desert and alkali flat habitat in the San Joaquin Valley, California, created an exceptionally high rate of trap failure. An easy-to-use, economical, and quick method to secure these traps against disturbance was needed. The development of the wicket was the solution (Figure 1).



FIGURE 1. Photograph showing use and transport of the wicket used to secure small mammal livetraps.

To insure that this holdfast was durable, it was made in the shape of the familiar croquet arch from cold rolled steel rod stock about 0.6 cm in diameter. This diameter allowed the wickets to be easily formed and yet maintain their shape during use. The stock material was first cut into 48 cm lengths and then bent to form the wicket. To manufacture the wickets, a length of pipe 18 cm long and 1.25 cm in diameter was placed into a vise such that only 18 cm of rod could be inserted into it. Grasping the remaining length of rod with a pair of vise-grip pliers, the rod was bent 90 degrees. The other end of the rod was then inserted into the pipe and also bent 90 degrees such that all bends lay in the same plane. The ends of the wicket were then sharpened on a grinding wheel.

To carry the wickets, a 5 by 10 cm board approximately 45 cm long was used to hold the wickets. By attaching a sliding, wooden slat to the carrying rope, the wickets were secured and easily transported in the field. Once one of these wickets was placed over the livetraps, dislodgement of traps by wind or livestock ceased to be a problem. The use of these wickets is recommended for any box-type small mammal traps where they may be subjected to high winds or disturbance by animals.

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NORTHWARD RANGE EXTENSION FOR THE STRIPED MARLIN

The capture of a striped marlin, *Tetrapterus audax*, in Winchester Bay, Oregon extends the known range of this species approximately 1050 km northward along the eastern Pacific coast. Previously the northern limit of the known nearshore range of this species was Point Conception, California (Fitch and Lavenberg 1971; Miller and Lea 1972; Eschmeyer, Herald, and Hammann 1983). Another striped marlin was subsequently captured 32 km southwest of Santa Cruz, California, approximately 300 km north of Point Conception.

The striped marlin captured in Winchester Bay, Oregon (lat 43° 44' N, long 124° 11' W) was sighted on 13 August 1981 by Ken Kent and Mark Gibbons, crew of the charterboat HOLIDAY TOO, while it was swimming near the surface in the bay approximately 3 km up the Umpqua River Estuary. Mr. Gibbons, using sportfishing gear, snagged the fish near its mouth and landed it. The specimen was later measured and identified by the junior author (Table 1). The marlin had a deep 10 cm long cut in the upper left side of its head; the origin of the wound was unknown. Such an injury may have caused disorientation and could explain why the fish was found wandering in the estuary.

The striped marlin captured 32 km southwest of Santa Cruz, California (lat 36° 53' N, long 122° 26' W) was landed on 5 September 1983 by Bernie Osberg while sportfishing on the charterboat RAINSONG. The fish was taken to the Capitola Pier where it was examined and measured by the senior author and two other persons from Moss Landing Marine Laboratories (Table 1). Robert N. Lea, California Department of Fish and Game, examined the specimen the next day, taking further measurements and making a species determination.

TABLE 1. Measurements (in cm) and Weights (in kg) for the Two Striped Marlin

Measurements	Winchester Bay specimen	Capitola specimen
Total length (w/bill)	250	—
Fork length (w/bill)	230	234.4
Lower jaw to fork (body length) *	—	204.8
Eye (post. edge) to origin of anal fin	—	131.0
Eye to caudal fork	—	172.8
Bill length *	47	56.2
Anterior height of first dorsal *	33	34.9
Pectoral fin length *	40	43.3
Pelvic fin length *	24	32.6
Greatest depth of body *	35	31.9
Weight	56	—

* Measurements follow Rivas (1956).

The occurrence of these two striped marlin north of their reported nearshore range may be explained by their distributional and migrational patterns, and the oceanic conditions of the respective regions prior to each catch. Striped marlin are distributed throughout the Pacific and Indian Oceans, with fish being caught by longline up to lat 47° N, long 140° W in warmer oceanic water (Howard and Ueyanagi 1965). Striped marlin landings in southern California fluctuate seasonally with peak catch rates from August to October when water temperatures are normally warmest in this region (Squire 1974). The catch distribution of *T. audax* in the eastern Pacific has been shown to be strongly correlated to both sea surface temperature (Squire 1974) and depth of thermocline (Hanamoto 1974), with the fish concentrating in waters warmer than 16.1° C. A record 2300 striped marlin were landed in southern California in 1959, just after the well documented "El Niño" episode of 1957–58 (Squire 1983).

The catch of the striped marlin in Winchester Bay was preceded by the seasonal onshore progression of oceanic waters causing warmer than normal sea surface temperatures along the Washington, Oregon, and northern California coasts. Monthly mean temperatures near Winchester Bay increased from 11.0° C in March 1981 (NOAA 1981a) to 14.4° C in August 1981 (NOAA 1981b).

The more recent catch of the striped marlin near Santa Cruz occurred during an extensive El Niño event. Historically El Niño events have resulted in high sea surface temperatures and northerly occurrences of many southern species of fishes (Radovich 1961, 1963; Squire 1983). This catch was accompanied by other sightings of marlin in the Monterey Bay area in October and November 1983 (Robert N. Lea, Calif. Dept. Fish and Game, pers. commun.). Monthly mean sea surface temperatures near Point Piños increased from 12.8° C in April 1983 (NOAA 1983a) to 17.7° C in September 1983 (NOAA 1983b). The monthly mean during September was 2.5° C higher than the climatological mean for this location (NOAA 1983b).

Since the range of the striped marlin is primarily limited to the warm water areas of the Indian and Pacific oceans, the warm water events that preceded each of these captures were thought to be largely responsible for the northward occurrence of these two striped marlin.

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OCCURRENCE OF A JUVENILE CALIFORNIA LIZARDFISH, *SYNODUS LUCIOCEPS*, IN WASHINGTON WATERS

The recent intrusion of warm water, known as "El Niño," along the Pacific Coast, has resulted in northward movements for a number of fish species. This note documents the catch of a juvenile California lizardfish, *Synodus lucioceps* (Ayres), in Washington, outside of its previously reported northern range of San Francisco Bay (Eschmeyer, Herald, and Hammann 1983; Miller and Lea 1972). The type locality for *lucioceps* is "probably . . . the Bay of San Francisco" (Ayres 1855).

On 12 July 1983, during a Washington State Department of Fisheries research cruise, a juvenile specimen of the California lizardfish was collected. This specimen (UW 21024, 62 mm standard length-SL) was captured with a 3 x 6 meter surface net during a five minute night-time tow in Southern East Passage, Puget Sound, Washington (lat 47°20'N, long 122°21'W). The specimen was identified by D. W. Nelson and T. W. Pietsch of the School of Fisheries, University of Washington, and later verified by R. N. Lea, California Department of Fish and Game, Monterey.

Other observations in 1983 of juvenile lizardfish beyond their normal range included two specimens obtained in trawl catches off Newport, Oregon and one caught in a trawl outside Humboldt Bay, California. The first specimen from Oregon, 46 mm SL, was captured on 6 April, the second, 100 mm SL, on 23 June (B. Mundy, College of Oceanography, Oregon State University, pers. commun.). The California specimen, 75 mm SL, was collected on 14 May (R. Fritzsche, Department of Fisheries, Humboldt State University, pers. commun.).

Prior to 1983, two California lizardfish were noted north of San Francisco Bay; both were adults. In 1975, a lizardfish was reported captured on hook-and-line at the mouth of Discovery Bay, Washington (B. Miller, School of Fisheries, University of Washington, pers. commun.). On 15 May 1979, a lizardfish, 410 mm SL, was collected from a trawl catch northwest of Klamath River, California (lat 41°30'; 60 fm) (R. N. Lea, pers. commun.).

The 1983 observations of juvenile California lizardfish are assumed to indicate temporary movements during unusual oceanographic conditions and not a permanent addition to the Northwest fauna.

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—Gary P. Gonyea and Steve F. Burton, Washington State Department of Fisheries, Olympia, WA 98504. G. P. Gonyea's current address is: 123 Marlborough St., Boston, Mass 02116. Accepted for publication October 1984.

THE SCALLOPED HAMMERHEAD, *SPHYRNA LEWINI*, IN COASTAL SOUTHERN CALIFORNIA WATERS: THREE RECORDS INCLUDING THE FIRST REPORTED JUVENILE

A juvenile scalloped hammerhead, *Sphyrna lewini*, was caught on 4 October 1984 off Will Rogers State Beach, Pacific Palisades, Los Angeles County, California (Figure 1). The shark was caught on hook-and-line by Mr. Ronald Bjorklund while surf-fishing at 1700 h and is deposited in the Natural History Museum of Los Angeles County (LACM 43737-1). It represents the first reported juvenile of *S. lewini* from California waters.



FIGURE 1. *Sphyrna lewini*, LACM 43737-1, 545 mm TL, female, caught off Will Rogers State Beach, California, 4 October 1984. Photo by J. DeLeon, LACM.

The data for this specimen are: 545 mm total length (TM), weight when caught "approximately three pounds"; 380 mm precaudal length; 165 mm predorsal length; female. Color after refrigeration and preservation in 10% formalin, uniform light gray dorsally with lateral shading of dark gray above gill slits; dark gray around eyes; first and second dorsal fins with dark edges, remainder of second dorsal fin lighter gray than body; edge of upper caudal-fin lobe dark around to notch; lower caudal-fin lobe with black tip; dorsal surface of pectoral fins gray, ventral surface white; tips of pectoral fins dark; pelvic and anal fins light gray; venter uniform white. Stomach was empty. The abdominal cavity and gills were free of parasites. Ectoparasitic copepods were present on fins and body.

The first record of *S. lewini* from California was a female, 262 cm TL, caught on 28 August 1977 approximately 21 km west of Santa Barbara, California (Fusaro and Anderson 1980). Subsequent to this record, two additional scalloped hammerheads were caught in 1983. Data for these unpublished records are: two females (UCSB #2 and #3), 228 cm and 249 cm TL; 168 cm and 180 cm precaudal length; 635 mm and 635 mm predorsal length; 48.6 kg and 66.8 kg; caught in 18 m of water by a 10.16 cm stretch bottom gill net off Goleta Point, Santa Barbara County, California; 30 September 1983 (S. Anderson, University of California, Santa Barbara, pers. commun.)

Castro (1983) stated that adult *S. lewini* "probably mature at about 180 cm" and it is presumed that the 1977 specimen reported on by Fusaro and Anderson (1980) and the two 1983 specimens were mature females. Clarke (1971) reported that the size range of 1,566 scalloped hammerhead pups caught in Kaneohe Bay, Oahu, Hawaii, was 395 to 895 mm TL ($x = 557$ mm TL). Growth studies of laboratory pond-reared *S. lewini* pups indicated that these juveniles were probably less than one month old when captured (Clarke 1971). Based on its size, presence of a mid-ventral umbilical scar, and data presented by Clarke (1971), the juvenile *S. lewini* caught off Will Rogers State Beach is less than one month old.

Clarke (1971) documented the use of Kaneohe Bay as a principal pupping ground for the scalloped hammerhead and catch data revealed that pups were present throughout the year, but were found in consistently larger numbers from May to October. There are no previously reported data indicating that the scalloped hammerhead has used inshore areas of southern California as a pupping ground. The recent warm-water phenomenon (the well-documented El Niño event of late 1982–84) in the eastern Pacific Ocean has resulted in northward range extensions for a number of more southerly occurring species. The recent capture of a *S. lewini* pup off the beach in southern California is an additional example of the northward displacement of normally a warmer-water fish and presents evidence that some displaced species may use southern California coastal waters as pupping or nursery grounds.

ACKNOWLEDGMENTS

I thank R. Bjorklund for the donation of the scalloped hammerhead pup and T. Bjorklund for information and help; S. Anderson (UCSB) for supplying data on the two unreported hammerheads; C. C. Swift, R. J. Lavenberg, and D. M. Cohen (LACM) for review of the manuscript; and F. G. Hochberg (Santa Barbara Museum of Natural History) for additional information and advice.

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—JEFFREY A. SEIGEL, SECTION OF ICHTHYOLOGY, NATURAL HISTORY MUSEUM OF LOS ANGELES COUNTY, 900 EXPOSITION BOULEVARD, LOS ANGELES, CALIFORNIA 90007. ACCEPTED FOR PUBLICATIONS NOVEMBER 1984.

BOOK REVIEWS

DIVING WITH UNDERCURRENT, AN IN-DEPTH GUIDE TO CONTEMPORARY SPORT DIVING.

Anonymous; Atcom, Inc., Publishers; 2315 Broadway, New York, NY 10024-4397; 141 p.; \$19.95 (including \$2.00 postage and handling); paperback.

DIVING WITH UNDERCURRENT is a collection of articles that originally appeared in UNDERCURRENT, a newsletter published for the recreational diving community. The book, like the newsletter, has a simple format. There are no photographs, and only a few line drawings and tables. It is the policy of the editors of the newsletter and the book not to include advertising.

What this book lacks in graphic sophistication, is made up for with the wealth of information contained between the paper covers. The subject matter is divided into nine sections, at least several of which should be read by every skin and scuba diver. The coverage of each section is diverse. For instance, the section on "Getting Away" includes suggestions on reducing the cost of diving vacations, a review of sunscreens, and organizing trips. Another section discusses the legal problems associated with leading dive tours and diving accident liability. Some sections deal with specific diver interest subjects, including sharks, and "Diving for Dollars", while others deal with subjects that should be of importance to any diver, such as "Safe Diving", "Getting Bent" (decompression sickness), and "The Joy of Diving".

The largest chapter is "Equipment", and it alone makes this book worthwhile. There are articles which rate depth gauges, fins, and breathing regulators. Another discusses the pros and cons of steel and aluminum scuba tanks. Other articles compare underwater photographic strobes and movie cameras, discuss buoyance compensators, and the use of contact lenses during diving. There is also useful information on the maintenance of dive equipment.

It is in the chapter on equipment that the no-advertisement policy is of real benefit to the individual diver. Whether reviews of equipment which appear in specialty, advertisement supported magazines are unbiased is a continuing debate. The reviews in this book compare objectively equipment from different manufacturers and give useful information that is necessary in making an intelligent decision on equipment selection.

The articles included are generally short, but comprehensive. They are written in an easy to read style, without an excessive amount of jargon. Any individual who is competent to dive can easily read this book. Sources for the authoritative and scientific articles are included.

One aspect of the book I particularly liked was the handling of subjects which are not always adequately covered in basic diving courses or in the general sport diving media. Each topics include sharks, and detailed information on why divers die. Such information is presented in DIVING WITH UNDERCURRENT in a manner that is instructional rather than emotional. As such, the information can be satisfactorily used even in basic scuba classes.

The price of \$19.95, includes postage and handling. Apparently, the book can only be obtained from the publisher. The price seems a little high, but when the limited audience and the book's contribution to diver safety and enjoyment are considered the cost is worth it. However, for a book of this price, I would like to see a better binding. The pages in my copy began to fall out before I had read half the articles.

I would also appreciate a complete list of the articles in the book, if not an index. I found it a little annoying to have to leaf through the book looking for an article on a particular subject.

DIVING WITH UNDERCURRENT is of specific interest to divers, and those interested in diving. It is a valuable source book that should be studied by all divers. I wholeheartedly recommend this book.—*Peter L. Haaker*

THE SHARKS OF NORTH AMERICAN WATERS

by Jose I. Castro. Drawings by D. Byron Stone III. Texas A&M University Press, 1983, 180 p. \$19.50 cloth, \$9.95 paper

This field guide is probably the most complete catalogue of sharks from North American waters to date. The 108 species accounts include the newly described megamouth shark from Hawaii as well as several rare deep-water species not yet recorded, but probably occurring, off North America. North American waters are defined as within 500 nautical miles of the United States and Canada and from the Arctic Ocean to 20° N latitude, including the Gulf of California and the Gulf of Mexico.

The author begins the book with a discussion of shark evolution, anatomy, reproduction, migration, fisheries, utilization and shark attacks. A family key utilizing narrative and drawings leads the reader into the individual shark descriptions. Each species description contains diagnostic characters, descriptions of similar species, distribution, biology, fishery methods and a list of references.

The geography range information should be used with caution as a comparison with Eschmeyer, Herald and Hammann (1983) for 15 species that commonly occur off California revealed several discrepancies, particularly in southern extensions of the range. For example: for the sixgill shark, *Hexanchus griseus*, the author gives California as the southern range on this coast; Eschmeyer *et al.* (1983) lists Baja California as the southern range. The northern range of the shortfin mako, *Isurus oxyrinchus*, listed by the author is California; Eschmeyer *et al.* (1983) lists Oregon as the northern range. Some of the other data also may not be up-to-date, considering the fact that the date of the most recent reference cited in the bibliography is 1980.

This field guide is further enhanced by the inclusion of 17 high quality color plates of living sharks; the whale shark photo is particularly noteworthy.

Despite the limitations of some of the geographical range data and the possible limitations of some of the other data because of more recent reports, I believe this book will prove to be a valuable and often used guide for biologists, fishermen, divers and naturalists.—*Daniel W. Gotshall*

Eschmeyer, W.N., E.S. Herald, and H. Hammann. 1983. A Field Guide Pacific Coast Fishes of North America. Houghton Mifflin Co., Boston, 336 p.

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